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P.O. Box 1046
Ottawa, Canada
K1P 5S9

C.P. 1046
Ottawa, Canada
K1P 5S9

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COMPREHENSIVE EVALUATION OF THE BERTHOLD LB1200 SURVEY METER

by

M.W. Davis
Monserco Limited

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Research repo

COMPREHENSIVE EVALUATION OF THE
BERTHOLD LB1200 SURVEY METER

ABSTRACT

The performance of two Berthold LB1200 survey meters was evaluated under the influence of a range of beta and photon radiation energies and environmental conditions likely to be encountered in the field. The survey meters responded satisfactorily to the range of beta particle and photon radiation energies emitted by most radioisotopes commonly used in Canada. The survey meters performed acceptably under most of the environmental conditions tested here with the exception of radiofrequency interference and electrostatic charge.

The x-ray/gamma energy response of the two meters in the range 0.059 to 1.33 MeV was found to be typical of geiger tubes. The efficiency (ratio of the meter reading to the true exposure rate in air) was 2 at 59 keV, increased to a maximum value of 3 at 85 keV, and dropped to a value of 1.2 at 200 keV. When a narrow beam of x-ray/gamma radiation was focussed onto only part of the geiger, the true exposure rate in the beam could be calculated within 20% by correcting the meter reading for linearity, efficiency and fraction of tube exposed. Beta particles with energies from 0.158 to 2.27 MeV were measured using the thin end window geiger. The efficiency for beta particles from C14 was approximately 10 times lower than for beta particles from Sr90.

There were no observable effects on the analog meter response of the two LB1200s from 1) temperature variations in the range -30 to +30 degrees C; 2) the relative orientation of the survey meters in the gravitational and magnetic fields of the earth and 3) relative humidity variations in the range 16% to 94%. Radiofrequency radiation in the range 30 Hz to 1 GHz was directed at all surfaces of the two survey meters. One meter exhibited an elevated count rate when rf interference in the range 30 to 1000 Hz was incident upon the bottom and side of the meter. When electrostatic potentials as low as 0.8 kV were put onto the plastic meter face, both meters exhibited pronounced impairment of meter needle movement.

During the operational battery test the survey meters were powered for 39 and 44 hours of continuous operation before the battery charge was depleted. The analog meter response to the constant radiation source was unaffected by dropping battery voltage until the last few minutes of the test.

RÉSUMÉ

Le rendement de deux radiamètres Berthold LB1200 a été évalué sous l'influence de diverses radioactivités bêta et photoniques et de diverses conditions environnementales pouvant être présentes sur place. Les radiamètres ont fonctionné de façon satisfaisante par rapport à la variété de radioactivités de particules bêta et photoniques émise par la plupart des radio-isotopes couramment utilisés dans les laboratoires canadiens. Les radiamètres ont fonctionné de façon acceptable dans la plupart des conditions environnementales verifiées ici, à l'exception de l'interférence de la radiofréquence et de la charge électrostatique.

La réaction des deux radiamètres aux rayonnements X et gamma dans la plage de 0,059 à 1,33 meV s'est révélée être typique des tubes Geiger. L'efficacité (rapport entre le relevé du compteur et le taux d'exposition réel dans l'air) était de 2 à 59 keV, augmentait à une valeur maximale de 3 à 85 keV, et diminuait à une valeur de 1,2 à 200 keV. Lorsqu'un étroit faisceau de rayonnements X/gamma est concentré sur une seule partie du compteur Geiger, le taux véritable d'exposition du faisceau peut être calculé à 20 % près si l'on corrige le relevé du radiamètre quant à la linéarité, l'efficacité et la fraction de tube exposée. Des particules bêta avec énergie variant de 0,158 à 2,27 MeV ont été mesurées à l'aide du compteur Geiger à fenêtre mince. L'efficacité pour les particules bêta provenant du C14 s'est révélée à peu près 10 fois plus faible que pour celle des particules bêta provenant du Sr90.

Les variations de température descendant à -30 et s'élevant jusqu'à +30 degrés Celsius n'ont eu aucun effet observable sur les relevés analogues des deux radiamètres LB1200. L'orientation relative des radiamètres dans les champs de gravitation et champs magnétiques de la terre n'a pas influencé les relevés. Ni l'un ni l'autre radiamètre n'a indiqué des effets observables pour une humidité relative variant de 16 % à 94 %. Un rayonnement de radiofréquence variant de 30 Hz à 1 GHz a été dirigé sur toutes les surfaces des deux radiamètres. L'un deux a indiqué un taux de comptage élevé et ceci s'est produit lorsque l'interférence rf variant de 30 à 1000 Hz était dirigée vers le bas et le côté du radiamètre. Lorsque des potentiels électrostatiques aussi faibles que 0,8 kV ont été mis sur la surface en plastique frontale des radiamètres, les deux radiamètres ont indiqué une diminution prononcée du déplacement de l'aiguille.

Durant l'essai des piles sous tension, les radiamètres étaient alimentés pour une période de 39 à 44 heures d'opération continue avant que la charge de la pile ne soit épuisée. Le relevé analogue du radiamètre à la source de rayonnement constante n'a pas été influencé par la baisse de tension des piles, sauf durant les dernières minutes de l'essai.

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1.0 INTRODUCTION

This report describes the methodology and results of a comprehensive evaluation of the performance of two Berthold LB1200 survey meters that accounts for the influence of energy response and environmental conditions likely to be encountered in the field. The response of the survey meters to a range of x-ray/gamma ray and beta particle energies was tested. Also, the influence on meter operation of temperature, humidity, continuous and pulsed radiofrequency fields, radiation field geometry, geotropism and electrostatic charge was investigated.

The LB 1200 meter, Figure 1.1, was designed to be used as a gamma/x-ray survey instrument and beta surface contamination monitor. The basic design was developed by Laboratorium Prof. Dr. Berthold in the 1960's and has remained unchanged since 1970. The meter includes an internal thin window geiger tube and plug for an optional external geiger tube. All of the tests described here were conducted using only the internal tube. The survey meter is designed to respond to gamma/x-ray radiation above 80 keV in the range 10uR/h to 100 mR/h. Contamination levels up to 30,000 counts per minute from beta particles with energy greater than about 50 keV can be monitored by opening the metalic slide window over the thin window geiger tube. The meter can be operated on rechargable batteries or using power supplied through the charger from a 120 VAC power source.

Two LB1200 survey meters, serial numbers 575339 and 575340, were provided by the AECB for the tests described above. In order to eliminate the complicating influence of decreasing battery voltage, both meters were supplied with power from chargers and 120 VAC power source throughout the tests. Meter response to decreasing battery voltage was investigated separately. The LB1200 meter output is erratic especially on the lower scales. Therefore, an external scaler was used to sum the electrical pulses produced by the Geiger-Mueller tube and precision was increased. Modifications to the survey meters also facilitated the remote measurement of battery voltage and enabled the remote switching on, off and battery test functions, see Appendix 1.

2.0 GAMMA/X-RAY ENERGY RESPONSE

The gamma/x-ray energy response of the two detectors was tested on range IV in the energy range 59 to 210 keV using an x-ray generator and at energies of 0.66 and 1.17/1.33 MeV using Cs137 and Co60 sources, respectively. The measurements of the radiation fields generated by these sources can be traced to national standards at the National Research Council (NRC) in Ottawa.

The x-ray radiation energies of 59,85,107,147,183 and 210 keV were generated using the Ontario Hydro MG320 Philips x-ray generator that has been calibrated for this purpose at Central Safety Services (CSS), Pickering. Using appropriate targets and filters the continuous x-ray spectrum is peaked at the energies indicated above. Ontario Hydro has checked the quality of these x-rays by the measurement of characteristic half-value thickness (Ref.1). During these tests the exposure rates in air were measured using the Ontario Hydro Ionex instrument, type 2500/3 s/n 1659, manufactured by Nuclear Enterprises Ltd. The Ionex has been calibrated at the NRC against national standards and is suitable for use as a secondary standard for measuring radiation exposure (Ref.2). The experimental arrangement is shown in Figure 2.4 and the results are recorded in Appendix 2.

The two LB1200 meters were tested at 660 keV using the 100 curie Cs137 source at Ontario Hydro CSS. The exposure rate in air around the source was measured with the Ionex instrument. The experimental arrangement is shown in Figure 2.4 and the results are recorded in Appendix 2.

The two LB1200 meters were tested at 1.17 and 1.33 MeV using the Co60 source in the Health Physics Department at McMaster University, Hamilton. The radiation field around the source was measured using the Farmer Dosimeter (model 2570A, s/n 4982, 600cc chamber model 2575, s/n 162) which had been compared to the Ontario Ministry of Labour ion chamber which itself had been calibrated by NRC and is therefore traceable to NRC national standards. The experimental arrangement is shown in Figure 2.4 and the results are tabulated in Appendix 2.

Each of the LB1200 instruments was calibrated at 30 mR/h (40 mR/h for Co60) on the 0-100 mR/h scale at each of the gamma/x-ray energies indicated above. In all cases the radiation was normally incident upon surface 1 as shown in Figure 2.1. The efficiency of each survey meter was calculated by dividing the exposure rate indicated on the LB1200 meter by the true exposure rate in air (milliroentgens/hour) measured using the Ionex or Farmer dosimeter. The efficiency was then plotted as a function of gamma ray quality for each instrument (Figures 2.2 and 2.3.) The range of fluctuation of the needle on the LB1200 meter is indicated by a vertical bar at each photon energy. The circles represent the efficiency calculated using the ratio of external scaler counts relative to Cs137.

During these measurements, the survey meters were supplied with power from the battery chargers (model LB-7615 fitted with 110 volt AC adapter). The battery voltages varied within the range 2.91 to 3.01 volts and had no effect on the results (see section 8).

The response of the two instruments was similar to a typical Geiger-Mueller tube. The maximum efficiency at 85 keV was about three times the relative minimum efficiency measured

at 0.66 MeV. Below 85 keV the efficiency decreased rapidly with decreasing x-ray energy. In the Berthold literature describing the LB1200, it is claimed that the energy dependence for gamma radiation is +/-20% between 0.1 and 1.5 MeV. This is definitely not true for radiation incident upon the front of the survey meter. Response to radiation incident upon the bottom of the survey meter was not tested in this study.

3.0 BETA ENERGY RESPONSE

The beta particle energy response of the two detectors was tested on range III in the energy range 0.158 to 2.27 MeV using the set of New England Nuclear Ltd. reference sources listed in the table A3.1 in Appendix 3. The average and maximum beta particle energies from each of these sources are listed in the same table. The radioactivity in each source is distributed over a circle 2.54 cm in diameter and the calibration in becquerels of these sources is traceable to National Bureau of Standards United States.

In turn, each beta standard source was placed under the open window of the detector. The surface of the source was placed at 0.7 cm below the detector window which would be equal to the distance between the detector window and a flat surface to be monitored for contamination (see Figure 3.1).

An external scaler was used to measure the count rate recorded by the LB1200 detector from each source. Each counting interval was one minute so that the precision of the count rate determination was equal to or better than 2% (i.e. 100% times the ratio of the standard deviation of the count rate to the count rate.)

Each beta source was measured three times using each meter and the results were recorded (see Appendix 3). The total activity in each source on the measurement date was calculated using the date and activity indicated by the manufacturer and the half life of each radioisotope. For each meter and each beta particle energy the efficiency was calculated by dividing the indicated count rate (counts per second) by the true activity of the source (disintegrations per second). The response curves are shown in Figures 3.2 and 3.3. The efficiencies calculated using the external scaler measurements are shown as open circles with radii equal to two standard deviations. The range of the fluctuations of the LB1200 meter needle are shown also in the form of error bars.

The efficiencies for the two survey meters are similar for high energy beta particles at 0.16 and 0.17 based upon scaler counts. At low beta particle energies the efficiencies are significantly lower at 0.020 and 0.034 for meters 39 and 40 respectively. This difference which is most pronounced at the low energies likely results from slightly different thickness

of window material in the geiger tubes. The LB1200 meter can be used to measure low energy beta particles from C14 although the efficiency is up to 10 times lower than for beta particles from Sr90. In the literature provided by Berthold, it is claimed that the sensitivity to extended surface contamination using the built-in probe is .02 nCi/cm2 C14. If a 2.5 cm diameter source containing 0.02 nCi/cm2 C14 were placed at the position shown in Figure 3.1, the LB1200 meter would show an increase of 4 counts per minute (218 dpm x 0.02 efficiency). This increase would be indistinguishable from the background reading of 20 to 40 cpm because of the erratic fluctuations of the meter needle. The minimum detection level is estimated to be 5 to 10 times the claimed value of .02 nCi/cm2 ie. 0.1 to 0.2 nCi/cm2.

4.0 TEMPERATURE RESPONSE

The influence of temperature on detector response was tested using the Ontario Hydro KTS environmental chamber at Pickering. The KTS chamber which operates at ambient air pressure, has an internal volume of 8 cubic feet and is capable of generating temperatures in the range -35 to +150 degrees centigrade.

A beta radiation source was taped against the open thin end window of each LB1200 in the chamber to provide a constant irradiation of each geiger tube. The temperature inside one of the detectors was monitored by a thermocouple. The chamber temperature was slowly varied from room temperature up to +30 degrees centigrade, then down to room temperature. The room temperature, -30 degrees C. to room temperature test cycle was carried out separately. The cycles took several hours to complete to allow the temperature within the survey meters to follow the chamber temperature. The detector response was recorded by noting both the deflection of the meter needle and recording the scaled pulses from the GM tube at intervals over the temperature range. The results are recorded in Appendix 4. The survey meters were operated on battery power alone throughout the experiment in order to most accurately duplicate field conditions. The survey meters were switched on to take readings at each temperature setting and remotely switched off between readings.

The relative response of each detector is plotted separately as a function of temperature in Figures 4.1 and 4.2. For meter 39, a statistically significant increase in the count rate was observed from the scaler data between 20 and 30 degrees C. The less accurate analog meter readings did not show the same effect. The response of survey meter 40 was observed to increase with decreasing temperature at 0.12% per degree C. in the range +20 to -30 degrees C. on the basis of scaler counts. Using the Student's T test the hypothesis that the slope was non-zero was calculated to be true at the 95%

confidence level. However, the less accurate analog meter readings exhibited no temperature dependence.

The response of the LB1200 analog meter is unaffected by temperatures in the range -30 to +30 degrees C.

5.0 HUMIDITY RESPONSE

The environmental chamber described above was also used to determine the survey meter response as a function of humidity. A beta source was taped against the open thin window of each LB 1200 meter to provide a known constant irradiation of each geiger counter throughout the test. At ambient room temperature and pressure, the humidity was slowly raised from ambient of 16% relative humidity (RH) to 94% and scaler and meter readings were recorded at regular intervals, see Appendix 5. Open pans of water were placed in the chamber to generate 100% RH however, this condition was achieved for only a few minutes. Condensation formed on the meters, but, their operation was not impaired. The KTS chamber door was opened and the relative humidity returned to 16%. Final scaler and meter readings were taken. Relative humidity was measured using wet and dry bulb thermometers and relative humidity tables. The cycling temperatures in the KTS chamber which are part of its normal operation caused variations in humidity that are represented graphically as horizontal bars.

The response of each detector was plotted separately as a function of relative humidity (Figures 5.1 and 5.2). Both meters exhibited no dependence on relative humidity.

6.0 RESPONSE TO RADIOFREQUENCY INTERFERENCE

The susceptibility of the LB1200 to radiofrequency interference was tested using procedures outlined in standards for industrial and process control equipment (and included in this report as Appendix 7). The meters were tested over the range of frequencies from 30 hertz to 1 gigahertz.

The power densities that were radiated onto the survey meters were equal to or greater than 20 mW/cm2 in the frequency range 30 Hz to 5 MHz. From 5 MHz to 1 GHz the power density was reduced to 1mW/cm2 because this is the threshold limit value for radiofrequency radiation recommended by the American Conference of Governmental Industrial Hygienists (Figure 6.1). Radiofrequency signal sources and antennae were set up to generate rf interference while sweeping through the frequencies from 30 Hz to 1 GHz, this includes the two common Walkie-Talkie frequencies of 50 and 450 MHz. Because of the wide range of radiofrequencies used in the test, several different rf generators and antennae had to be used. Therefore the full

frequency range was divided into 7 sweeps as shown in Appendix 6. The strength of the interference was checked over the full range of frequencies indicated using a field strength monitor. The LB1200 meter was positioned in the radio field at the location where the field strength had previously been measured and the scaler rate was recorded for each sweep. The duration of each sweep starting at the low frequency limit and ending at high frequency limit was one minute. During each sweep the scaler integrated the counts for a period of one minute. The results are shown in Appendix 6. A total of twelve sweeps over each frequency interval were made per instrument; two mutually orthogonal electromagnetic polarizations were directed onto each of the six different surfaces of the survey meter (Figure 2.1).

6.1 Continuous Wave Interference

The susceptibility of the LB1200 to continuous wave rf interference was tested using the procedure described above. A 1 kHz sine wave was used to modulate the rf signal at 90%. Experimental data are presented in Appendix 6.

6.2 Pulsed RF Interference

The susceptibility of the LB1200 to pulsed radiofrequency interference was tested using the procedure described in section 6.0. A 10 kHz square wave was used to modulate the rf signal at 90%. Experimental data are presented in Appendix 6.

6.3 RF INTERFERENCE RESULTS

The response of survey meter 39 was unaffected by the radiofrequency interference radiated upon it at 20 mW/cm2 from 1 Hz to 5 MHz and at 1 mW/cm2 from 5MHz to 1GHz.

The response of survey meter 40 exhibited interference when pulsed rf radiation in the range 30 to 1000 Hz was directed upon the surfaces 4 and 6 at a power density of 20 mW/cm2. The tests were repeated and the rf power density was reduced until the interference disappeared at 5 and 9.5 mW/cm2 on surfaces 4 and 6 respectively (Table 6.1). Surfaces 4 and 6 have metal conducting penetrations of the plastic case for the battery charger and slide window respectively which may contribute to interference. No conclusions were reached for the difference in interference effects on the two meters.

7.0 RESPONSE TO ELECTROSTATIC CHARGE

The influence of electrostatic charge on the LB1200 response was investigated. The movement of the analog meter needle was monitored after an electrostatic charge had been put onto the meter face and measured using an Anderson Static meter.

Static charge was applied to the LB1200 by rubbing the face of the meter with tissue paper and the deflection of the meter needle noted under the following conditions:

a) The meter needle was deflected to about half scale by the presence of a radioactive source, the static charge was applied and the radioactive source removed. The needle either returned to the bottom of the scale or remained at the deflected position, pinned by static.

b) The meter needle was positioned near the bottom of the scale and the static charge was applied. Then a radioactive source was brought near the geiger tube. The needle either deflected upscale or was pinned at the bottom of the scale by static.

Electrostatic potential was measured using an Anderson Effects Inc. static meter model DCA - 1200 - 1. It has a stated accuracy of +/-10% of full scale and can measure zero to +/-5kV at 6 inches.

The response of the analog meter needle on instrument 39 was unaffected by the application of an electrostatic potential of 2.2 kV. However, upon application of 5 to 6 kV the needle movement was drastically impaired. The needle would "stick" at zero and not move upscale when a radioactive source was brought near the end window. Because the charge was unevenly distributed on the meter face, the needle would move up or down part of the scale but would not move freely over the whole scale.

The movement of the meter needle on instrument 40 was unaffected by the an electrostatic potential of 0.8 kV. However, a charge of 2.5 kV pinned the needle in some places and restricted its movement in others.

8.0 RESPONSE TO BATTERY DISCHARGE

The response of the LB1200 detector to decreasing battery voltage was determined for each of the two meters. After fully charging the batteries a beta radiation source was taped to the open thin end window of the geiger tube. The meter was switched on and left on until the batteries were discharged to the point where the survey meter indicated zero. Meter readings, battery voltage and GM pulse rate were measured and

recorded as a function of time until battery discharge.

The data have been plotted in Figures 8.1 and 8.2 for meters 39 and 40 respectively. Both meters responded in a similar manner to decreasing battery voltage. When first switched on, the battery voltage dropped quickly to between 2.5 and 2.6 volts and remained at that level for about 30 hours. Shortly thereafter with the battery charge depleted, the battery voltage dropped sharply. The response of both meters (exhibited by both the analog meter reading and the scaler output) show no effect due to decreasing battery voltage until the very end when the voltage dropped precipitously.

With battery voltage as low as 1.30 and 1.15 volts (meters 39 and 40 respectively) the geiger tubes continued to operate at the same efficiencies as at higher voltages. The battery check on the LB1200 meter showed 130, just above the K at 125, in both cases. At the final reading the battery checks were below the K and the geiger tube outputs were zero as reflected in both the analog meter and scaler readings. It can be concluded that the voltage check on the LB1200 provides a reliable indication of the battery status.

The Berthold literature describing the LB1200 states that the fully charged battery will provide 10 hours of continuous operation. This was shown to be a very conservative statement as the meters operated continuously for 39 and 44 hours in these tests.

9.0 LINEARITY TEST

The response of the LB1200 meters as a function of meter needle deflection (linearity) was investigated using the Co60 source. The Farmer dosimeter was used to measure the true exposure rate in air at 30 cm from the Co60 source and the distances for all other exposure rates were calculated using the inverse square law. The LB1200 was positioned at appropriate distances from the source so that the true exposure rate corresponding to needle deflections of 5, 20, 40, 60, 80 and 95 per cent of full scale could be determined. The measurements were repeated for all ranges on both meters. The gamma radiation was incident on surface 1 as shown in Figure 2.1. The potentiometers for each range were adjusted in an attempt to set the 20% full scale in each range to read the true exposure rate in air. These attempts were not always successful, mainly due to the influence on one scale of potentiometer adjustments on the other scales.

The results of the measurements are plotted as a function of true exposure rate in air in Figures 9.1 to 9.4. Some of the ranges on both meters had significant non-linear responses. The variations in response are attributable to the age of and differences in electrical components switched into the circuit

on each range.

The response of meter no.39 was observed to be linear on all ranges except no. IV. On the latter range indicated exposure rate exceeded true exposure rate and the percentage error increased with increasing meter reading. The response on ranges I, III and II was linear within the accuracy of the measurements and the slope of the latter curve was ideal at 1.0. However, the slopes of the response curves on ranges I and III were significantly below and above the ideal respectively at 0.678 and 1.12.

The response of meter no. 40 was observed to be linear on all ranges within the accuracy of the measurements. The response on range II was ideal with a slope of 1.0, however, the responses on range I and IV were below the ideal (slopes 0.798 and 0.93 respectively). The response on range III had a slope of 1.133 and was above the ideal.

10.0 RESPONSE TO PARTIAL DETECTOR IRRADIATION

The internal geiger tube in the LB1200 is a cylindrical detector with an active volume having dimensions 3.7 cm in length and 2.78 cm in diameter. A thin metallic slide covers the thin end window on surface 6 and the geiger tube is oriented within the meter as shown in Figure 2.1.

Under some circumstances radiation fields to be measured may be non-uniform and the geiger counter in the LB1200 may only be partially irradiated. In order to assist a field operator to interpret the significance of some meter readings under conditions of partial detector irradiation, the following slit and pencil beam measurements were carried out.

10.1 Slit Beam Geometry

A radioactive source of Co60 was aligned with a 0.64cm (1/4") wide gap between two lead collimators as shown in Figure 10.1. The LB1200 was positioned immediately behind the lead collimators and was oriented so that the 0.64cm (1/4") wide and 10 cm long beam impinged upon the front of the survey meter (surface 1 in Figure 2.1). The height of the beam exceeded both the diameter and length of the cylindrical geiger counter. The slit/source geometry allowed a beam divergence of only 0.29 degrees. Therefore, the beam width at the centerline of the geiger tube was 3.4% greater than the 0.64cm slit width.

The slit beam was directed along the longitudinal axis of the geiger tube as shown in Figure 10.2 (a). For two additional measurements the beam was offset 0.9 cm to the left and to the right of the longitudinal axis. The results of

measurements in these three configurations are given in Table 10.1.

The survey meter was turned onto its side and the slit beam was directed across the diameter midway between the ends of the geiger tube as shown in Figure 10.2 (b). Also, the beam was offset from the first position 0.9cm towards each end of the geiger tube for two additional measurements. The results of these measurements are also given in Table 10.1.

10.2 Pencil Beam Geometry

A pencil beam of 3/8" diameter was generated using radiation sources and collimator arrangements similar to that shown in Figure 10.1 except that the penetration through the lead shield was a circular hole of 3/8" diameter.

The pencil beam was directed through the front, surface 1, of the LB1200 as shown in Figure 10.3. Measurements were made with the beam directed at the center of the diameter midway between the ends of the geiger tube and at spots centered 0.9 cm above, below, to the right and to the left of center. The results of the measurements using 1.17/1.33 Mev gamma rays from a Co60 source are given in Table 10.2. The measurements were repeated using 85 keV x-rays from the CSS x-ray machine. These results tests are given in Table 10.3.

The true exposure rates in air in the slit and pencil beams were measured for both 85 keV x-rays and 1.17/1.33 MeV gamma rays. The radiation field around the Co60 source shown in Figure 10.1 had been measured previously at a distance of 30 cm using the Farmer Dosimeter. The true exposure rate in air at a distance of 1.27 metres was calculated to be 4.34 mR/h using the inverse square law. The exposure rate in air in the 85 keV x-ray beam was measured using a thermoluminescent dosimeter (TLD) (Panasonic UD801AS) that was smaller in diameter than the beam. The TLD was calibrated by irradiating the 600 cc Ionex chamber and three TLDs with 85 keV x-rays for the same time and at the same distance.

10.3 Discussion Of Beam Measurements

For each of the irradiation geometries investigated, a correction factor has been calculated by dividing the true exposure rate in air by the indicated exposure rate on the meter. The use of the correction factor allows calculation of the true exposure rate in air using the survey meter reading. However, one must know details concerning the radiation characteristics because the correction factor is shown to be beam geometry, gamma energy and meter dependent.

The results of the slit beam irradiation of the geiger tube shown in Table 10.1 are consistent with what one would expect. The highest meter reading occurs when the beam is incident upon the longitudinal axis. When the beam is radially offset 0.9 cm to the left or right the meter reading drops to 76 and 82% of the maximum. When the beam is directed across the diameter of the geiger tube the meter reading is lower because less of the geiger tube is exposed. However, the results of all three measurements with the beam directed across the diameter of the tube at different longitudinal positions are similar because the same volume of geiger tube is irradiated in each case.

The irradiation of the LB1200 geiger tubes by pencil beams also illustrates that the response of the tube is constant over its length as the results of top, center and bottom measurements are similar. When the pencil beam is directed 0.9 cm to the right or left of center the meter response drops to 77 to 83% as a smaller volume of the chamber is irradiated.

The response of the detectors to the 85 keV pencil beam was about three times higher than the response to the 1.17/1.33 MeV pencil beam from Co60. This is a consequence of the gamma energy response characteristics of the geiger tubes which were investigated and are presented in Figures 2.2 and 2.3. The tubes response to irradiation of 100% of the tube volume by 85 keV gamma rays is almost three times as large as the response to irradiation by 1.17/1.33 MeV gamma rays under similar conditions.

The volumes of the LB1200 geiger tube that were intersected by each of the pencil and slit beams were calculated and then expressed as fractions of the total active volume of the geiger tube (see Table 10.4 and Figures 10.4 and 10.5). Using the results of each of the beam/geiger tube measurements shown in Tables 10.1 to 10.3, the observed meter reading was corrected for linearity, using the curves in Figures 9.1 to 9.4, and for efficiency using curves from Figures 2.2 and 2.3. The efficiency and linearity corrected exposure rates were then divided by the true exposure rate in each beam and the results are given in Table 10.4 and presented graphically in Figures 10.4 and 10.5. In all but one case the exposure rate ratio is about 20.% higher than the volume ratio. Thus, the meter reading under conditions of partial irradiation of the geiger tube is directly proportional to (within 20%) the fraction of the active volume of the tube irradiatied.

11.0 GEOTROPIC AND GEOMAGNETIC RESPONSE

The response of the two LB1200 survey meters was tested for affects due to survey meter orientation in the earth's magnetic and gravitational fields. A beta radiation source was taped against the open thin end window of each of the LB1200

meters. Each meter was then positioned in all possible orientations with respect to the earth's gravitational and magnetic fields and the analcg meter and remote scaler readings were taken and recorded. The analog meter face was first oriented parallel to the earth's surface, face up, and two readings were taken with the meter pointing in orthogonal directions. The analog meter face was oriented parallel to the earth's surface, face down, and two more readings were taken with the meter pointing in orthogonal directions. The analog meter face was then oriented perpendicular to the earth's surface, plane A, and two readings were taken with the meter pointing in orthogonal directions. Finally, the meter face was oriented perpendicular to the earth's surface and perpendicular to plane A. Two readings were taken with the meter pointing in orthogonal directions. The raw data have been plotted for both survey meters in Figure 11.1. Open circles represent the scaler counts with two standard deviations of counting statistics shown. The vertical lines without the circles represent the range of needle fluctuations on the analog meter.

It is apparent that the two survey meters tested are not influenced by the relative orientation of the survey meter to the gravitational and magnetic fields of the earth.

12.0 CONCLUSIONS

The two Berthold LB1200 survey meters tested here responded satisfactorily to beta radiation with energies from 0.158 to 2.27 MeV and x-ray/gamma radiation in the energy range 59 keV to 1.33 MeV. For most radionuclides commonly used in Canada, the meters can be used to make beta contamination measurements and gamma radiation surveys. Exposure rates in narrow x-ray/gamma beams can be calculated within 20% by correcting the meter reading for linearity, efficiency and volume fraction of tube exposed.

The two survey meters performed acceptably under most of the environmental conditions tested here with the exception of radiofrequency interference and static charge. There were no observable effects on the analog meter response of the LB1200s under the influence of 1) temperature variations in the range -30 to +30 degrees C.; 2) the relative orientation of the survey meters in the gravitational and magnetic fields of the earth and 3) relative humidity variations in the range 16% to 94%.

Berthold's design of the LB1200 has successfully minimized the electrical power requirements for the portable survey meter. After fully charging the rechargeable batteries up to 44 hours of continuous operation was measured. The analog meter response was not influenced by the dropping battery voltage until the last few minutes of the test.

13.0 REFERENCES

1. Philips MG320 x-ray Half Value Layer Test Results
   Internal Ontario Hydro Report, July 24, 1981,
   Lopez, S. Central Safety Services, Pickering.

2. Calibration of Ionex Instrument (S/N 1659), PXNR-2670
   Henry, W.H., National Research Council.
   Oct. 21, 1983

FIGURE 1.1

LB1200 SURVEY METER

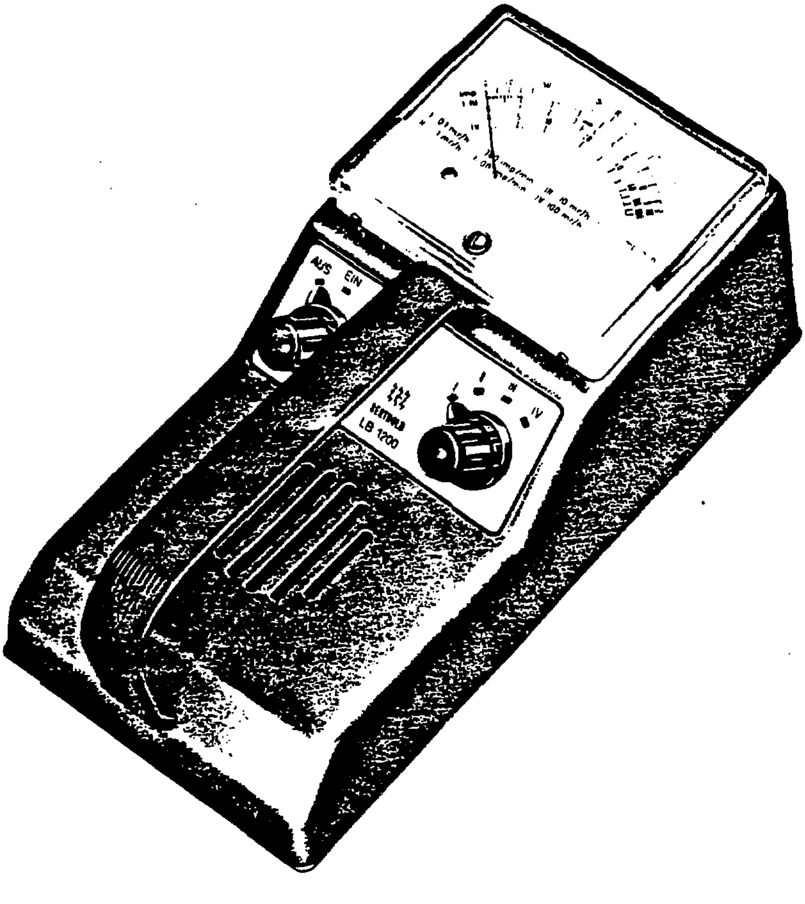


FIGURE 2.1

LB1200 SURVEY METER AND SURFACE DESIGNATIONS

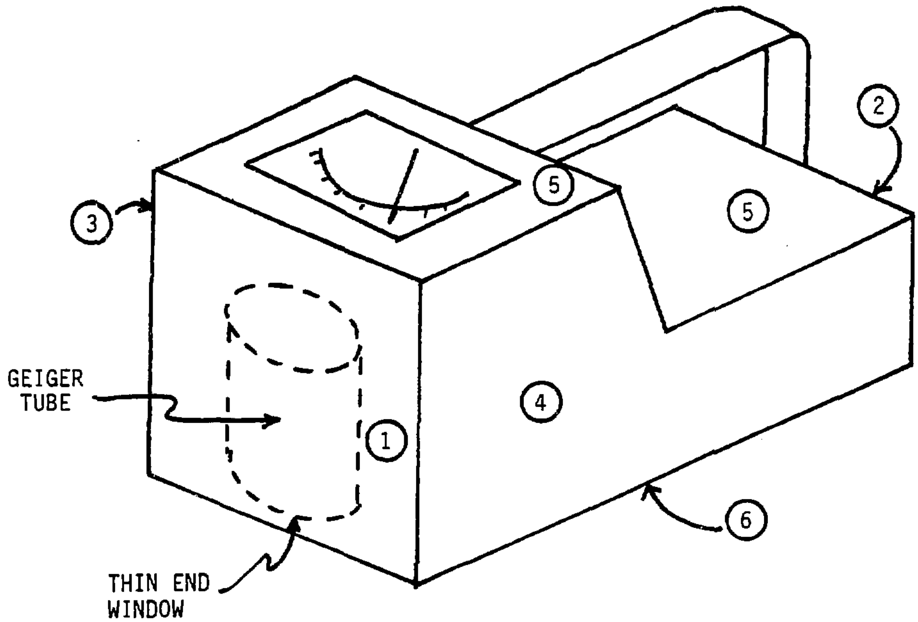
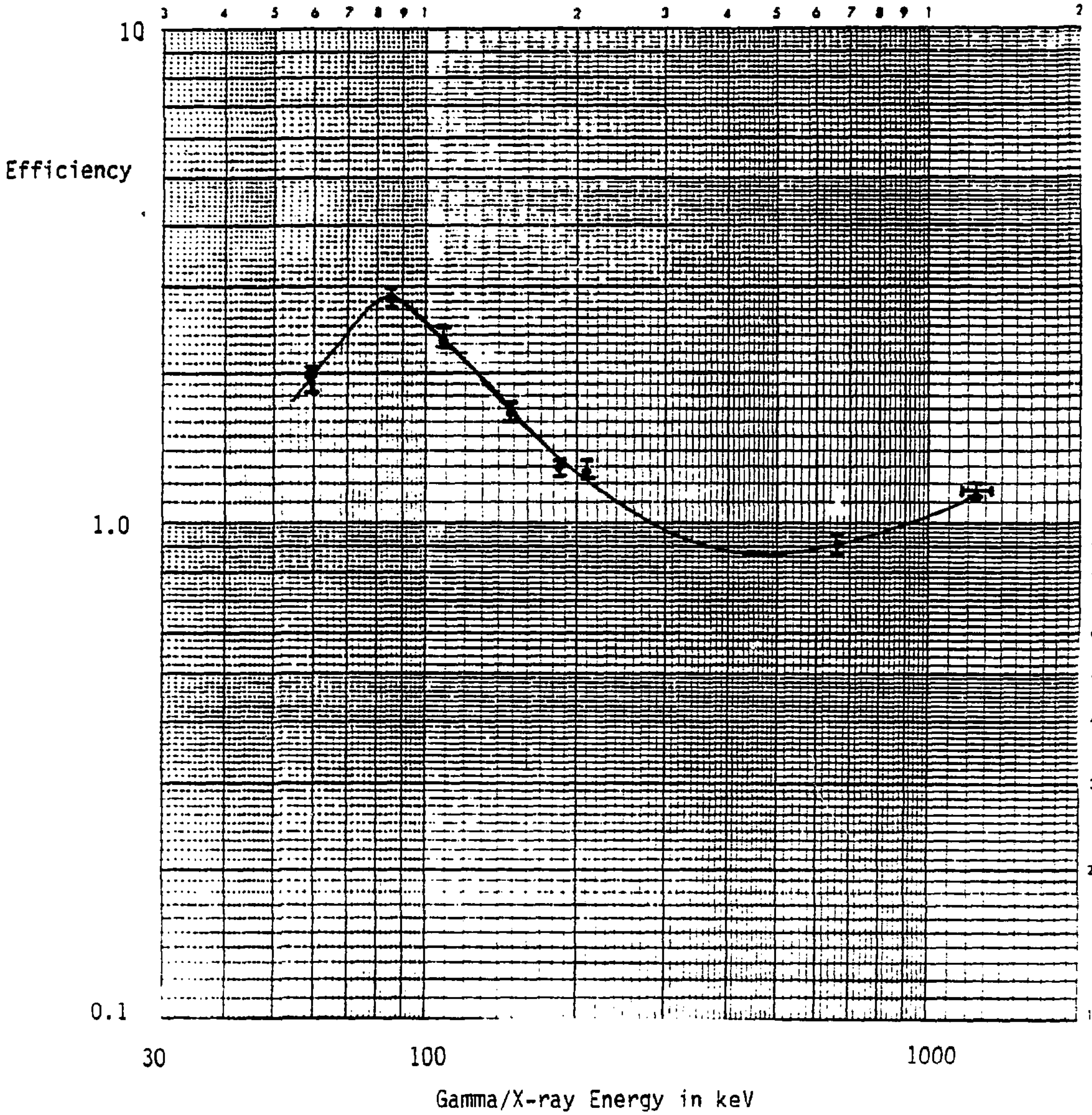


FIGURE 2.2

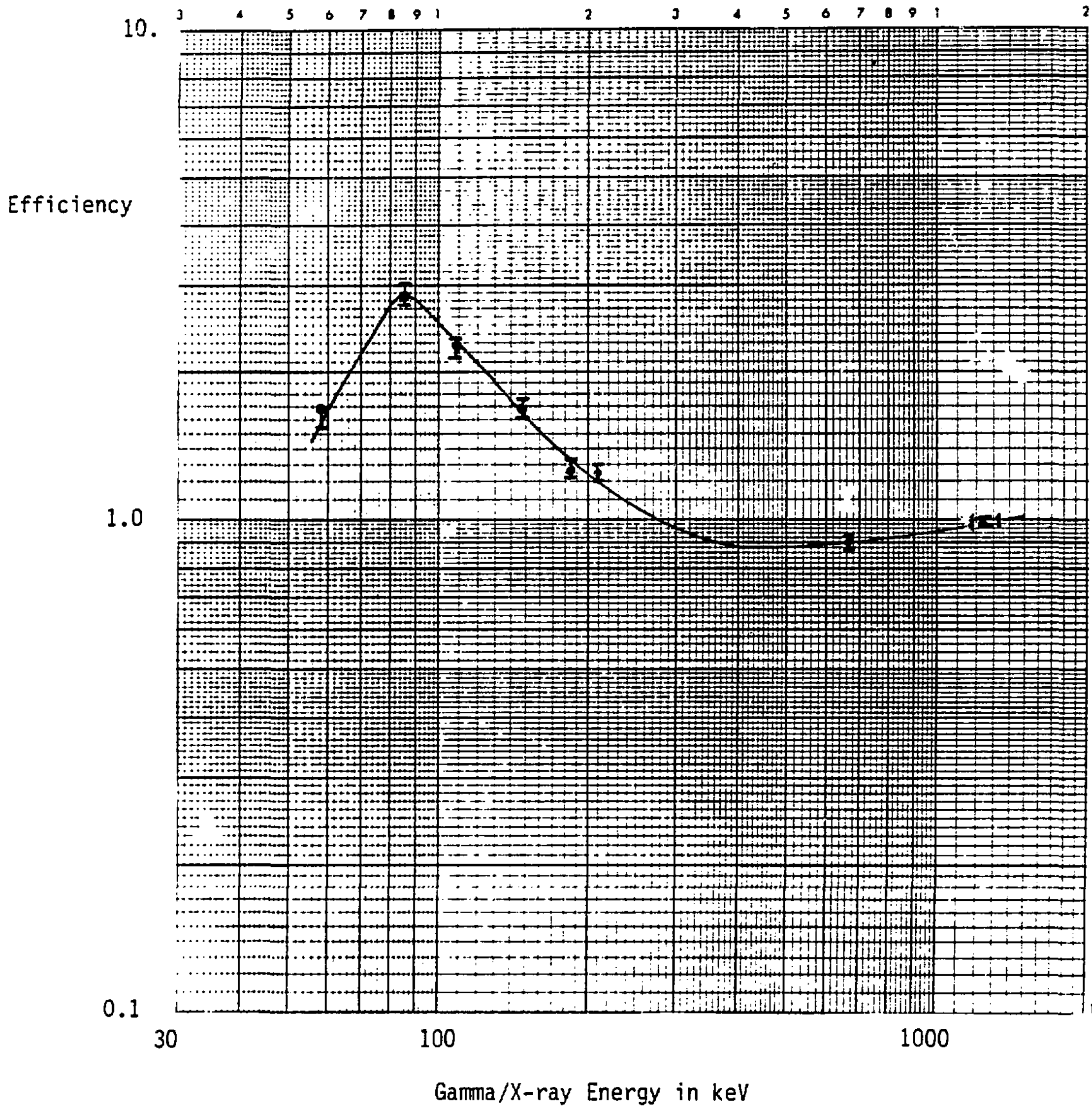
GAMMA/X-RAY ENERGY RESPONSE OF LB1200 SURVEY METER #39



$$\text{Efficiency} = \frac{\text{indicated mR/h on meter}}{\text{true exposure rate in air mR/h}}$$

FIGURE 2.3

GAMMA/X-RAY ENERGY RESPONSE OF LB1200 SURVEY METER #40



$$\text{Efficiency} = \frac{\text{indicated mR/h on meter}}{\text{true exposure rate in air}}$$

FIGURE 2.4

EXPERIMENTAL SETUP FOR GAMMA/X-RAY MEASUREMENTS

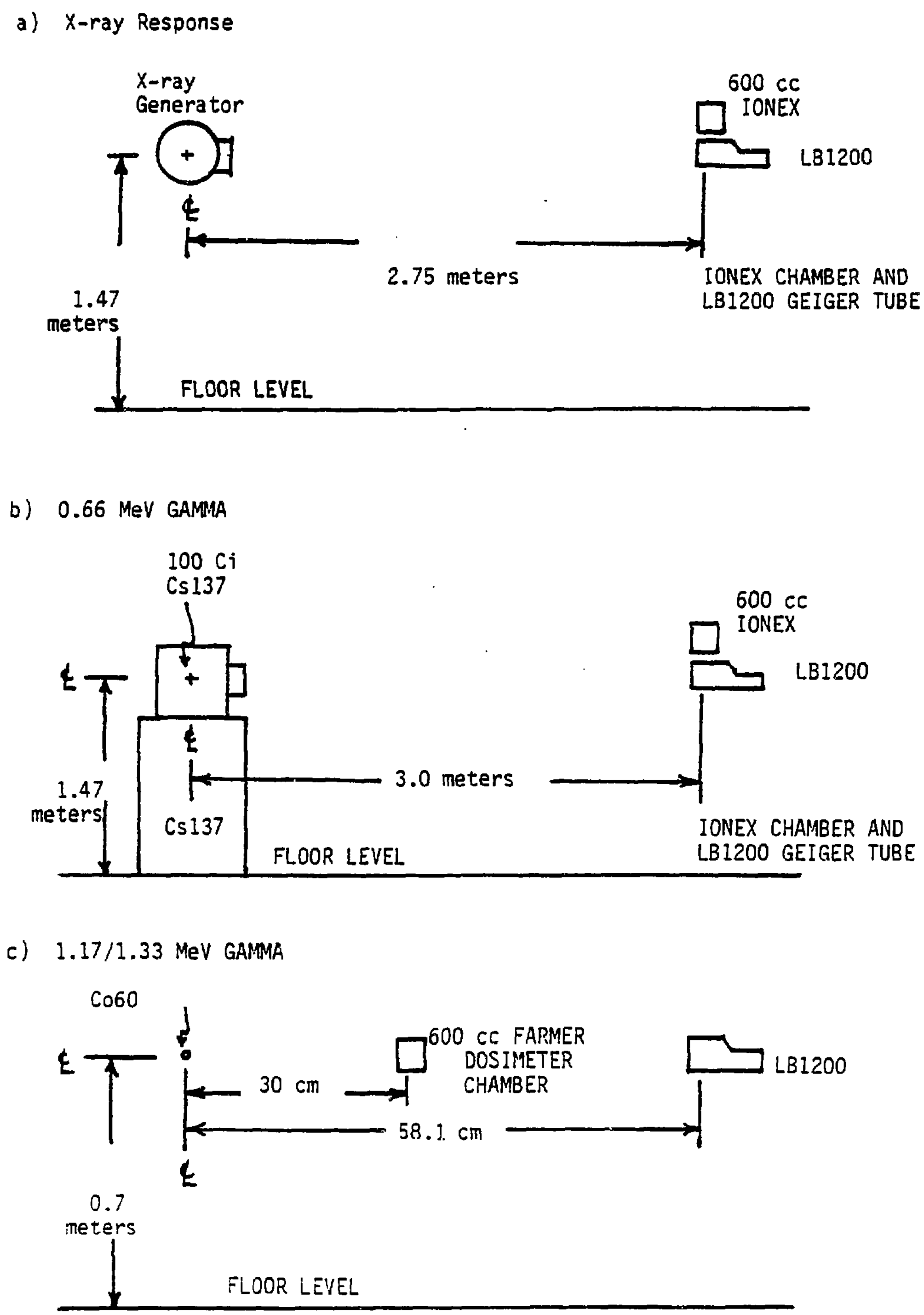


FIGURE 3.1

GEOMETRY FOR BETA ENERGY RESPONSE

MEASUREMENTS

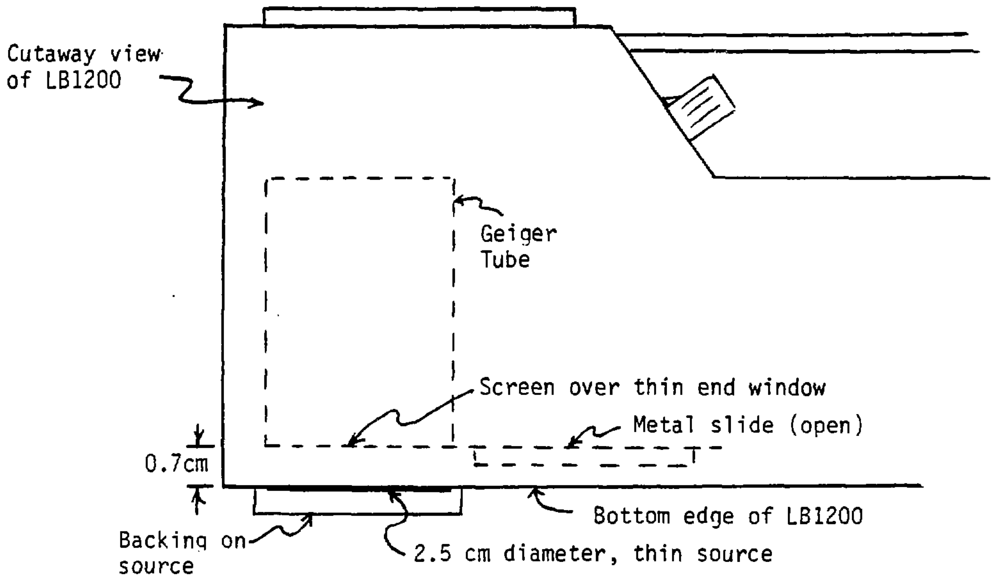
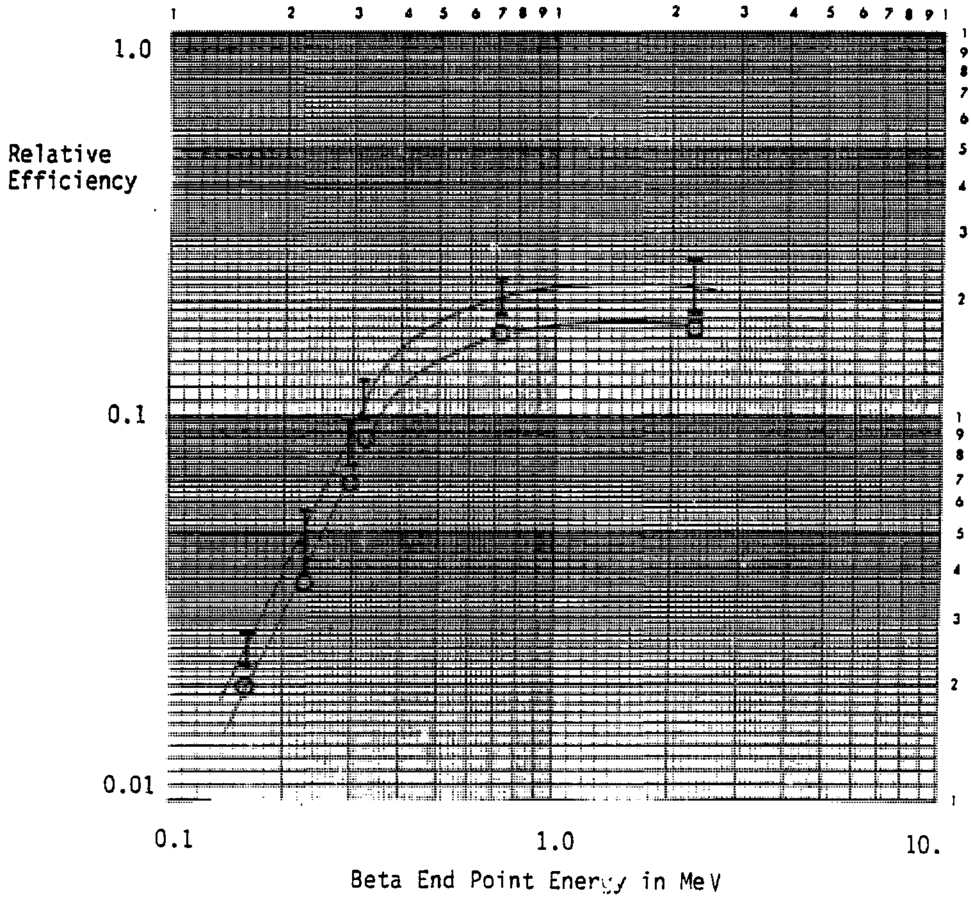


FIGURE 3.2

BETA ENERGY RESPONSE CUP'7E METER #39

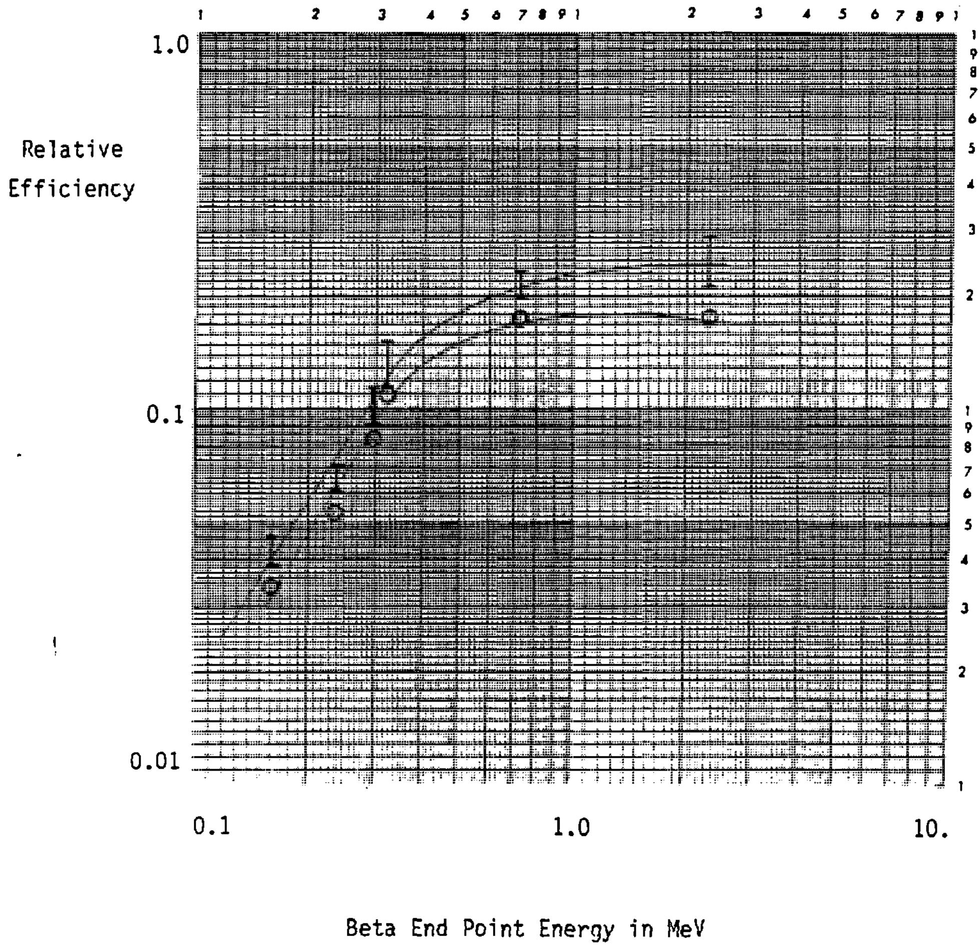


I range of LB1200 meter fluctuations

O based upon scaler measurements

FIGURE 3.3

BETA ENERGY RESPONSE CURVE METER #40



I range of LB1200 meter fluctuations
0 based upon scaler measurements

FIGURE 4.1

TEMPERATURE RESPONSE OF LB1200 SURVEY METER #39

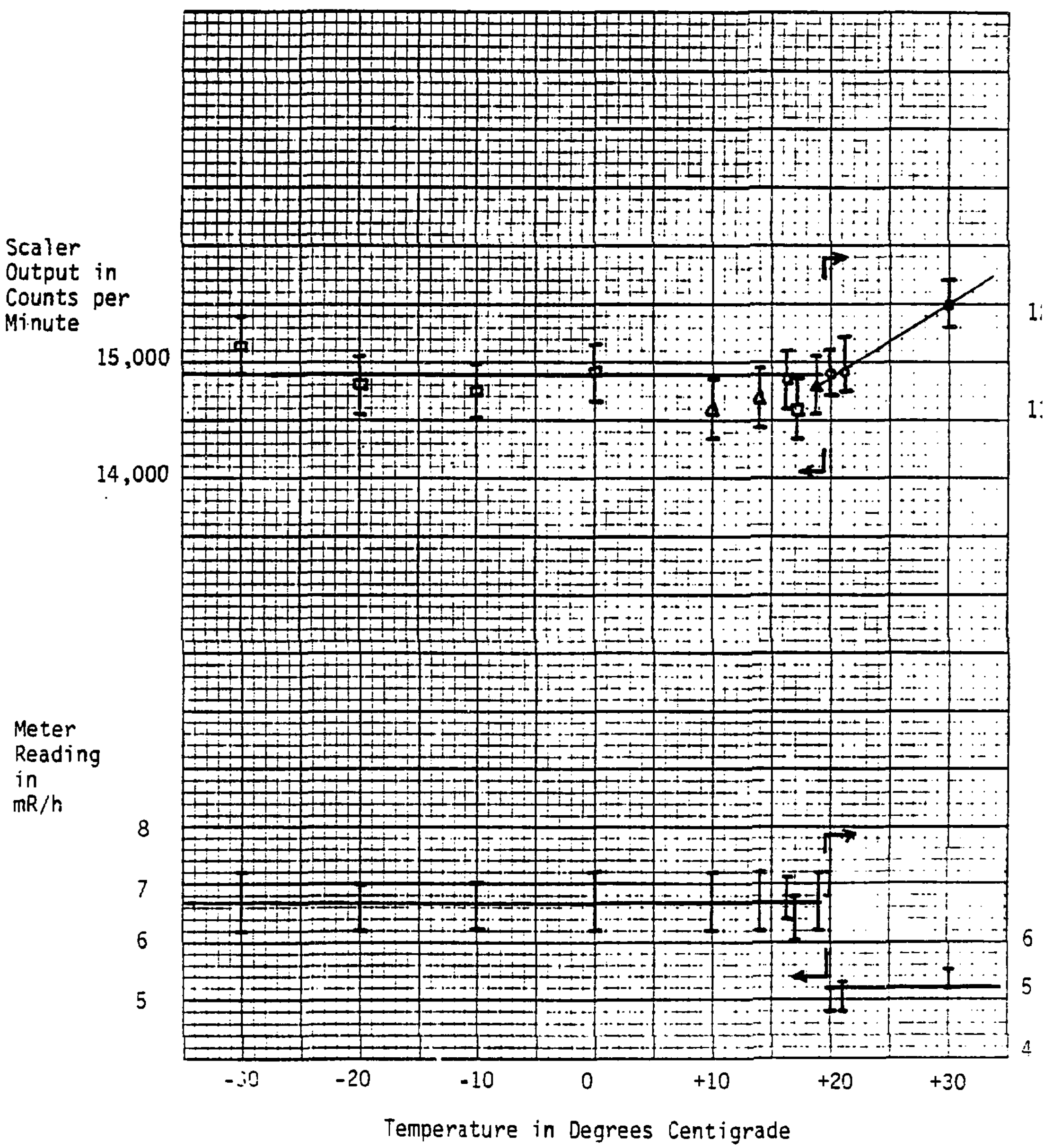


FIGURE 4.2

TEMPERATURE RESPONSE OF LB1200 SURVEY METER #40

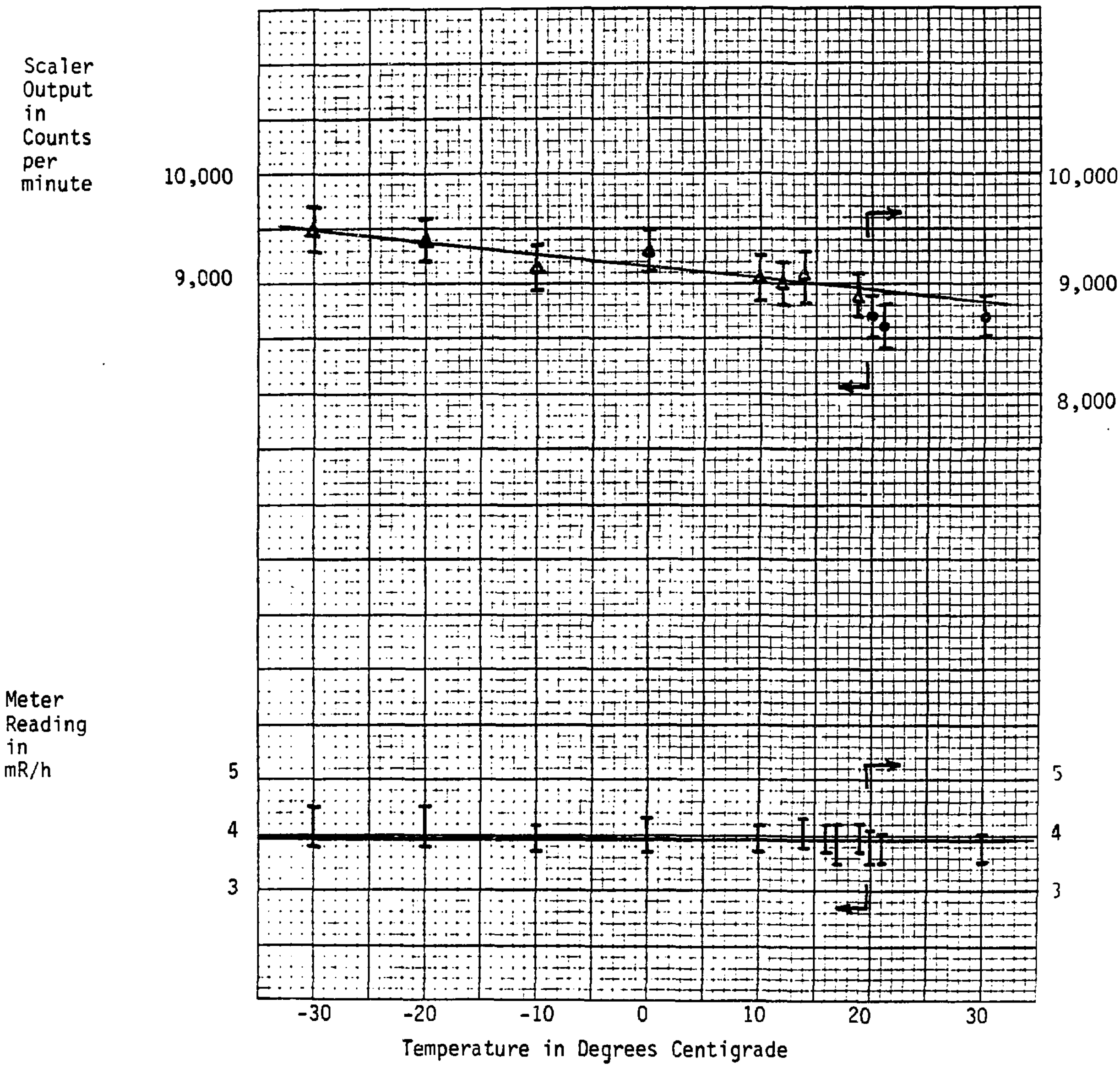


FIGURE 5.1

HUMIDITY RESPONSE OF LB1200 SURVEY METER #39

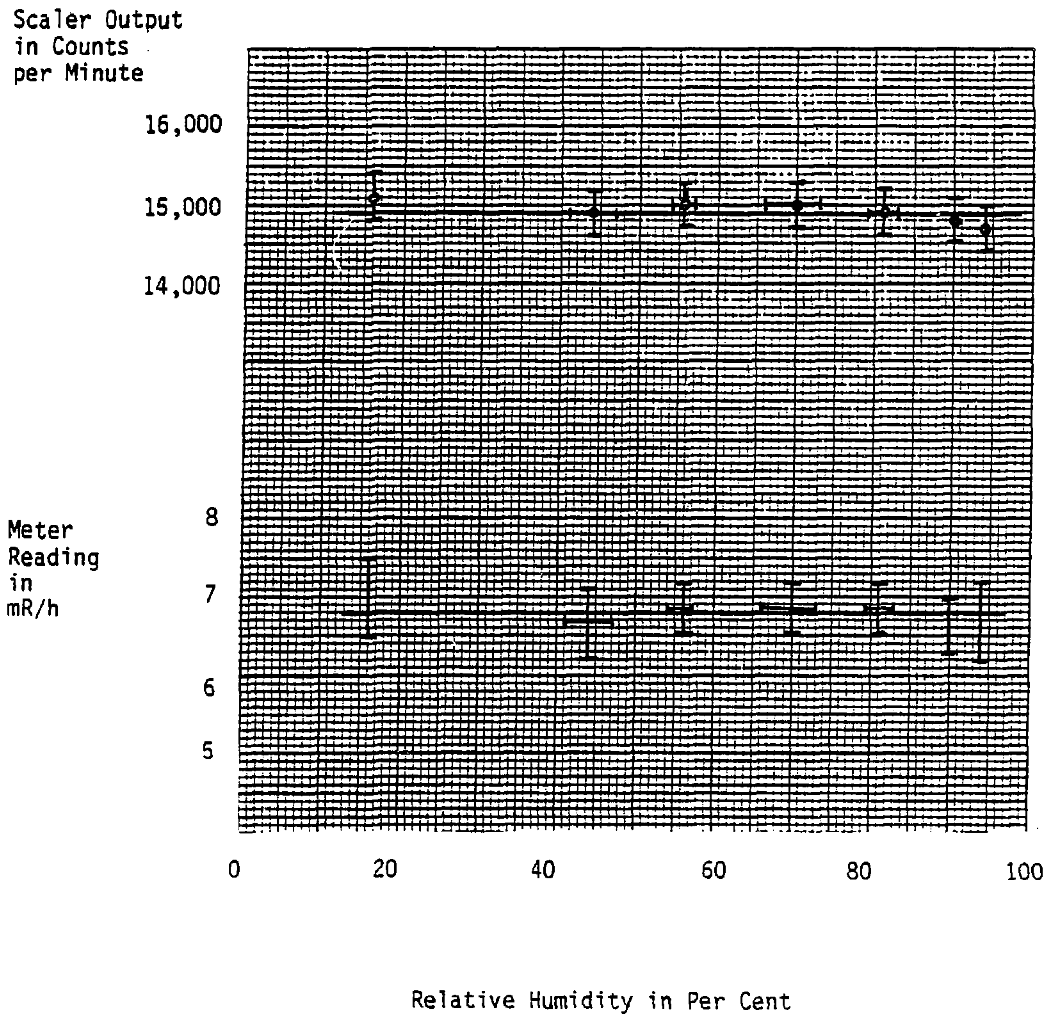


FIGURE 5.2

HUMIDITY RESPONSE OF LB1200 SURVEY METER #40

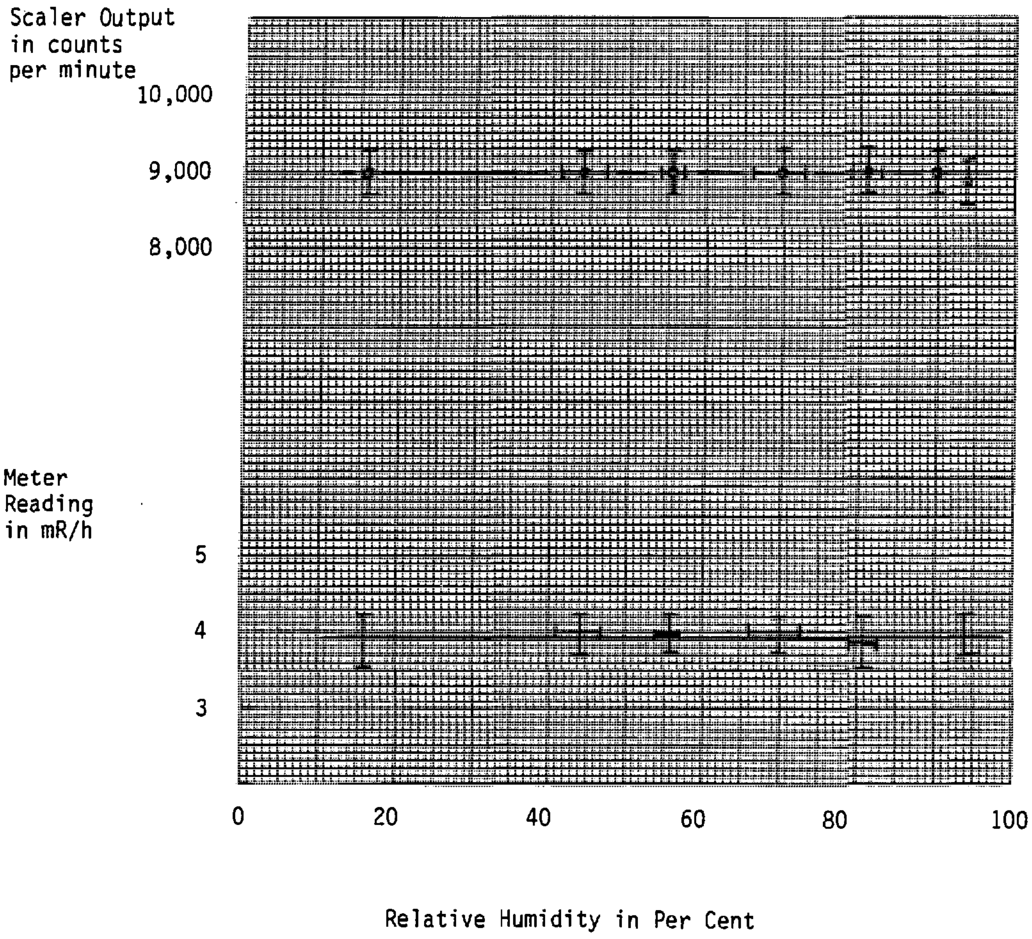
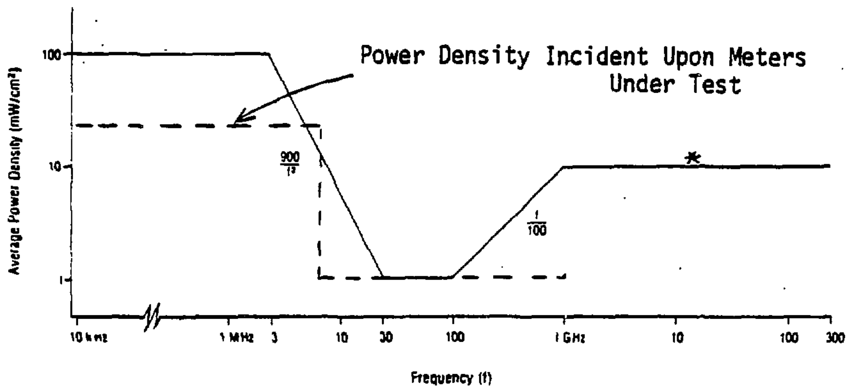


FIGURE 6.1

POWER DENSITIES OF RADIOFREQUENCY RADIATION USED

TEST LB1200 SURVEY METERS



* Threshold Limit Values for Radiofrequency/Microwave Radiation in the Workplace (from American Conference of Governmental Industrial Hygienists' TLV Guide 1984-1985).

FIGURE 6.2

RESPONSE OF LB1200 TO RADIOGREQUENCY INTERFERENCE

FREQUENCEY RANGE 30 to 1000 HZ VERTICAL POLARIATION

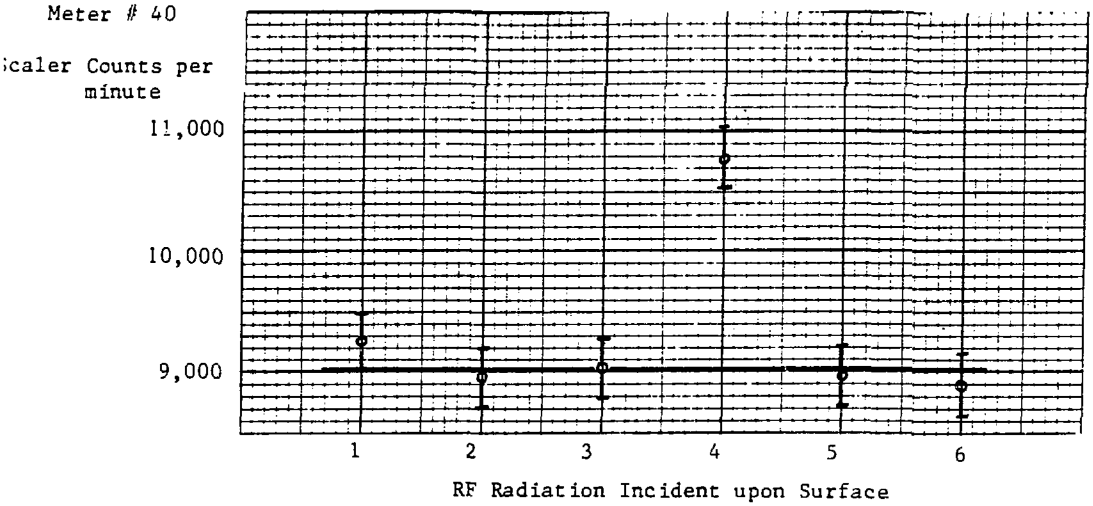


FIGURE 8.1

RESPONSE OF LB1200 SURVEY METER #39 TO BATTERY DISCHARGE

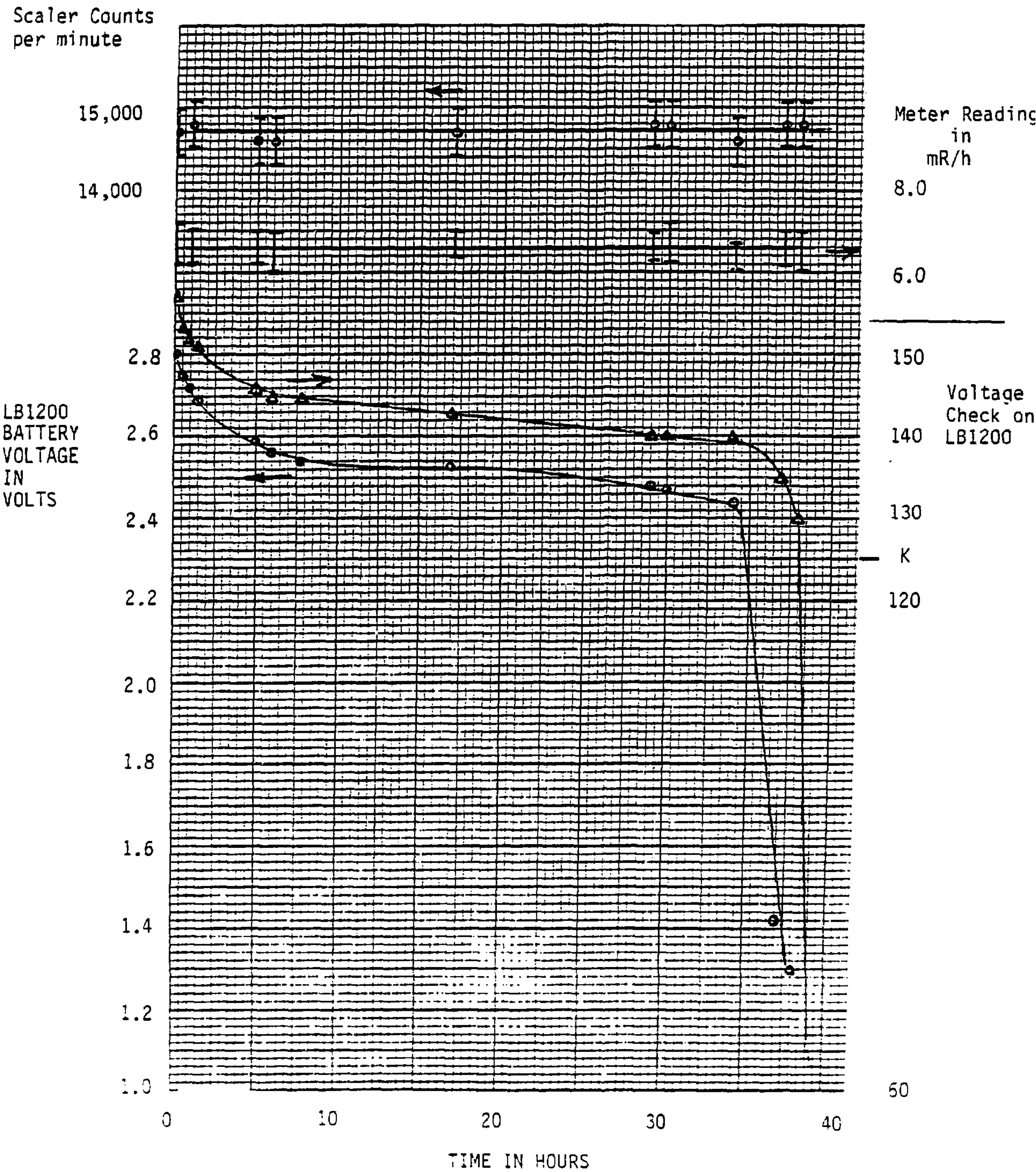


FIGURE 8.2

RESPONSE OF LB1200 SURVEY METER #40 TO BATTERY DISCHARGE

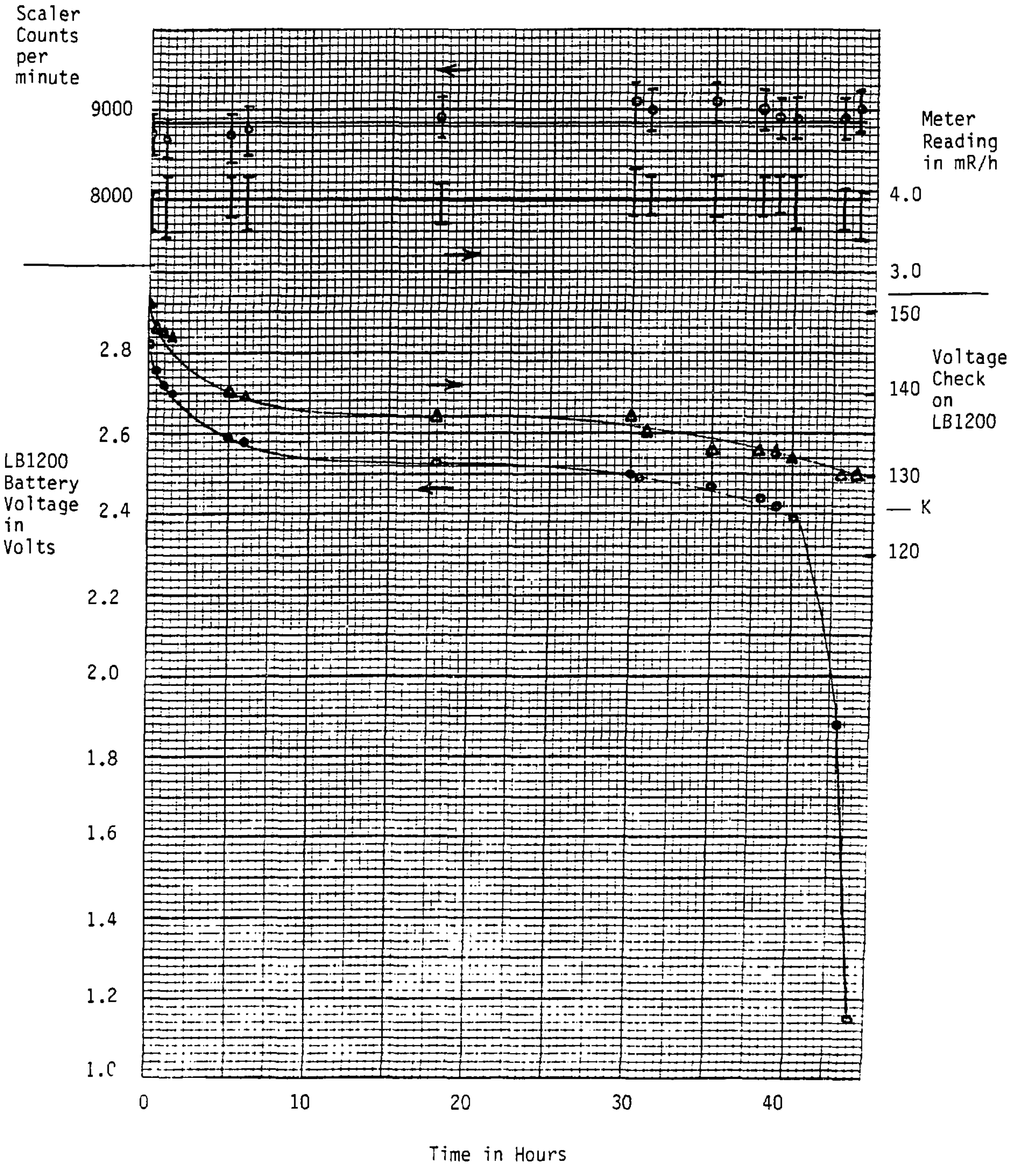


FIGURE 9.1

LINEARITY TEST OF LB1200 #39 RANGES III & IV

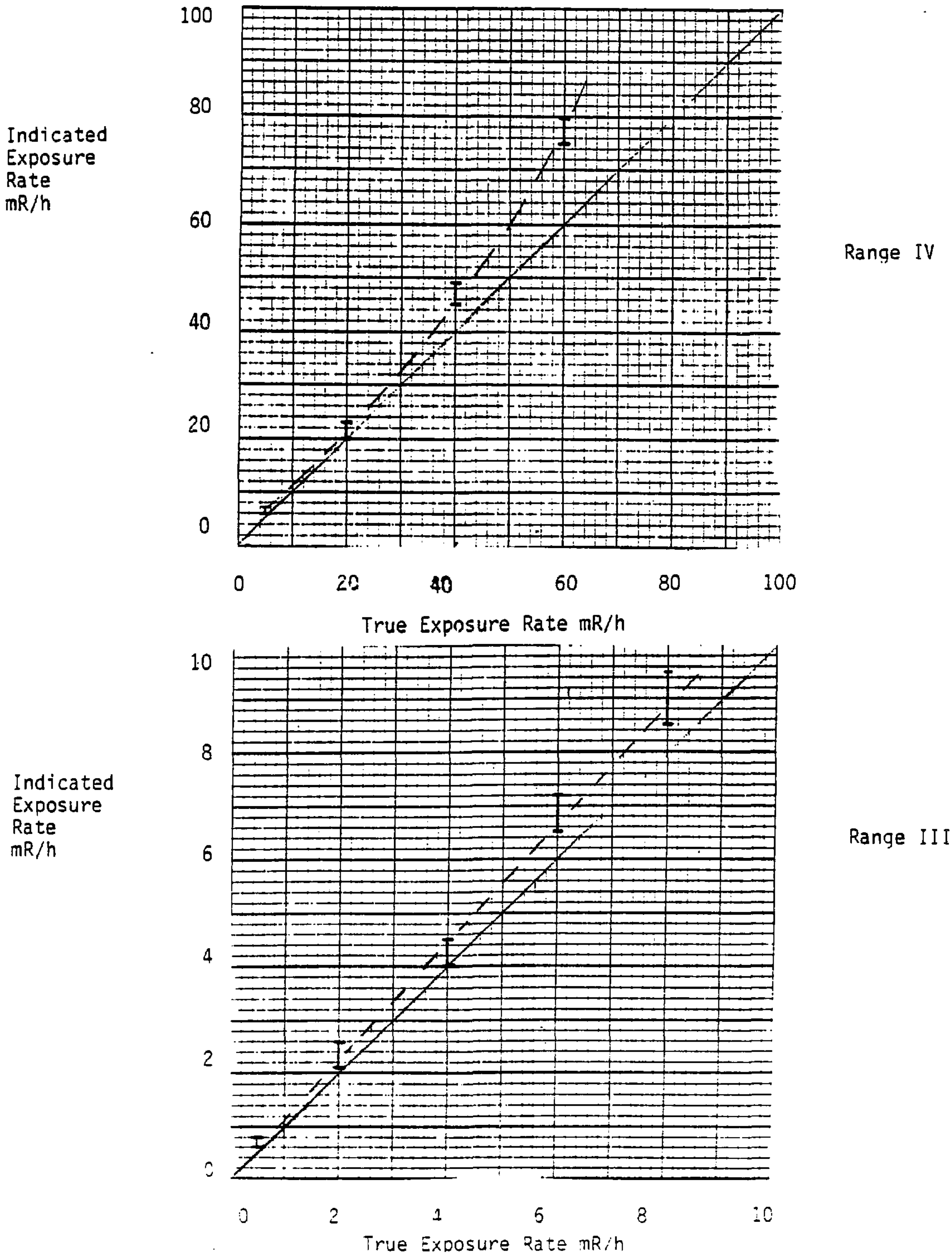
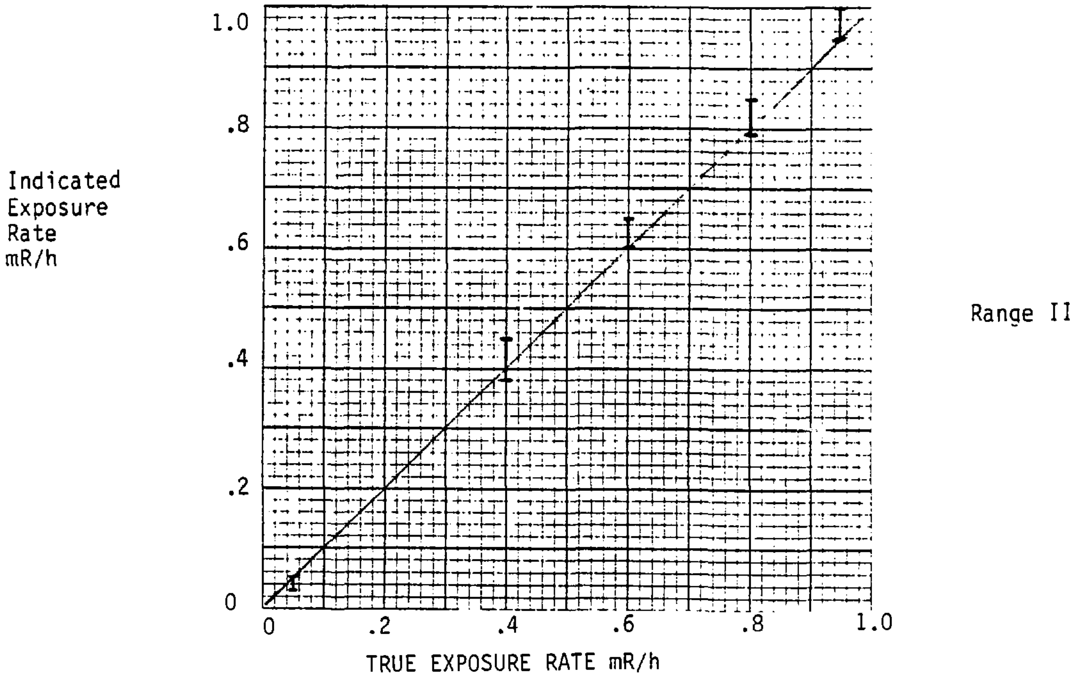


FIGURE 9.2

LINEARITY TEST OF LB1200 #39 RANGES 1 & II



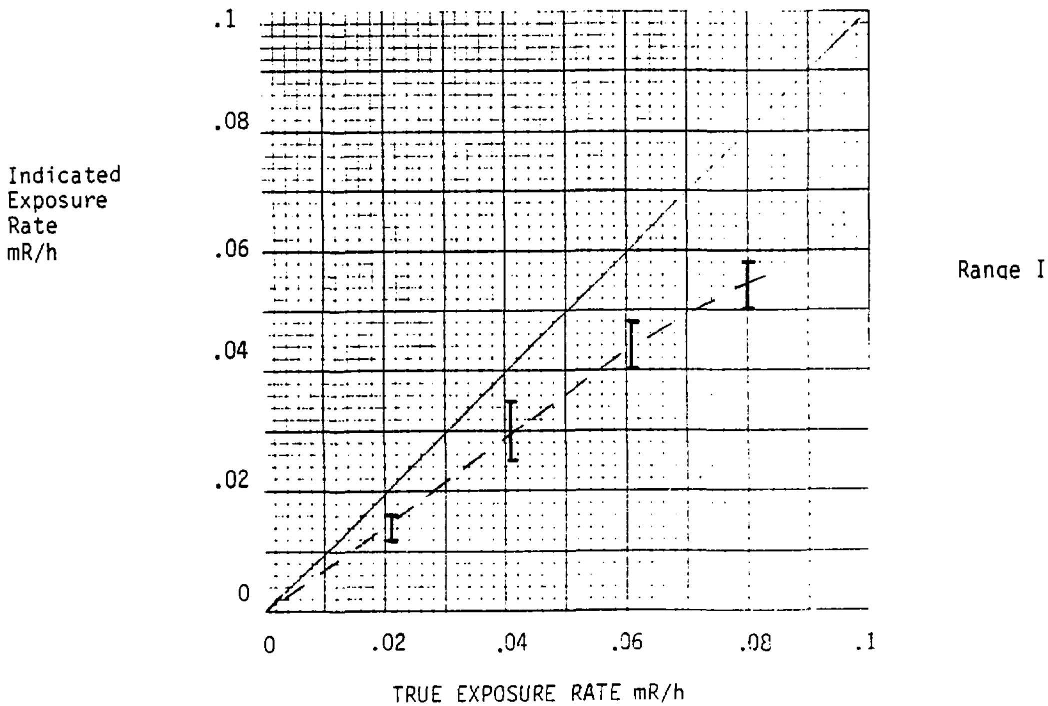
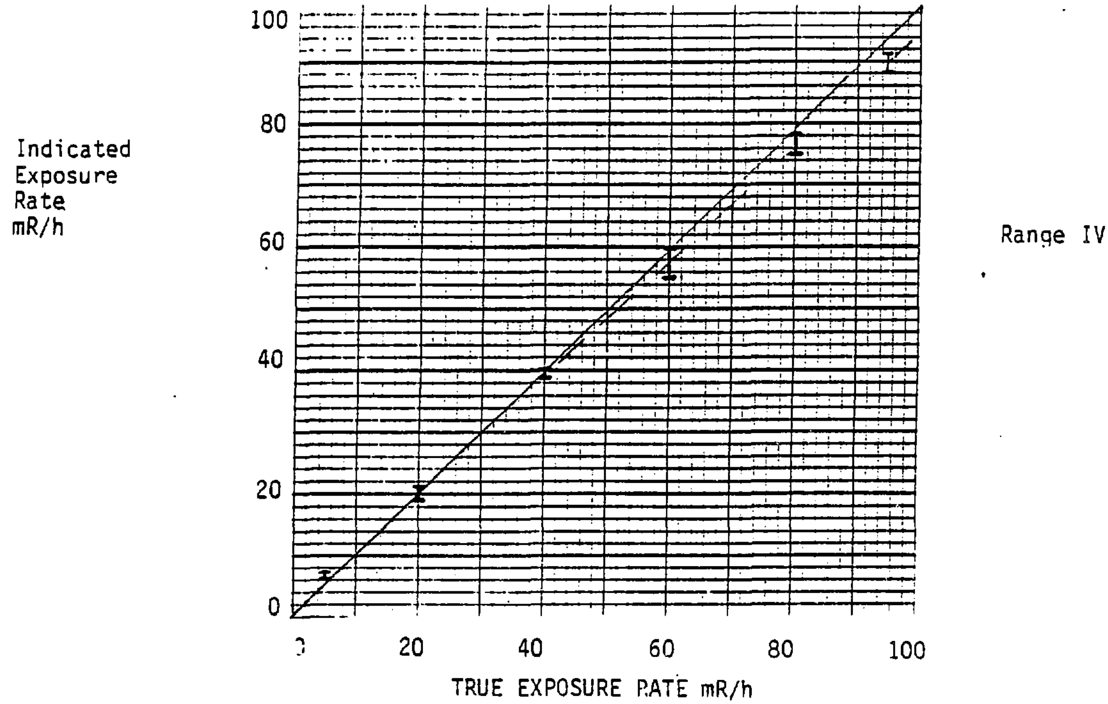


FIGURE 9.3

LINEARITY TEST OF LB1200 #40
RANGES III & IV



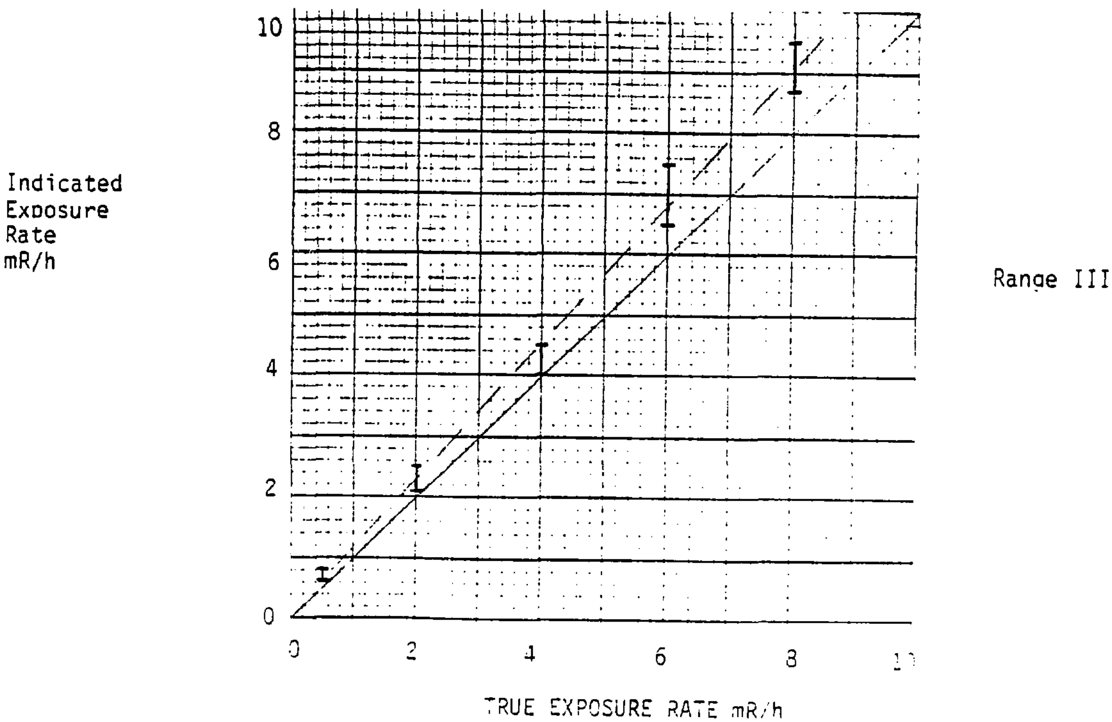
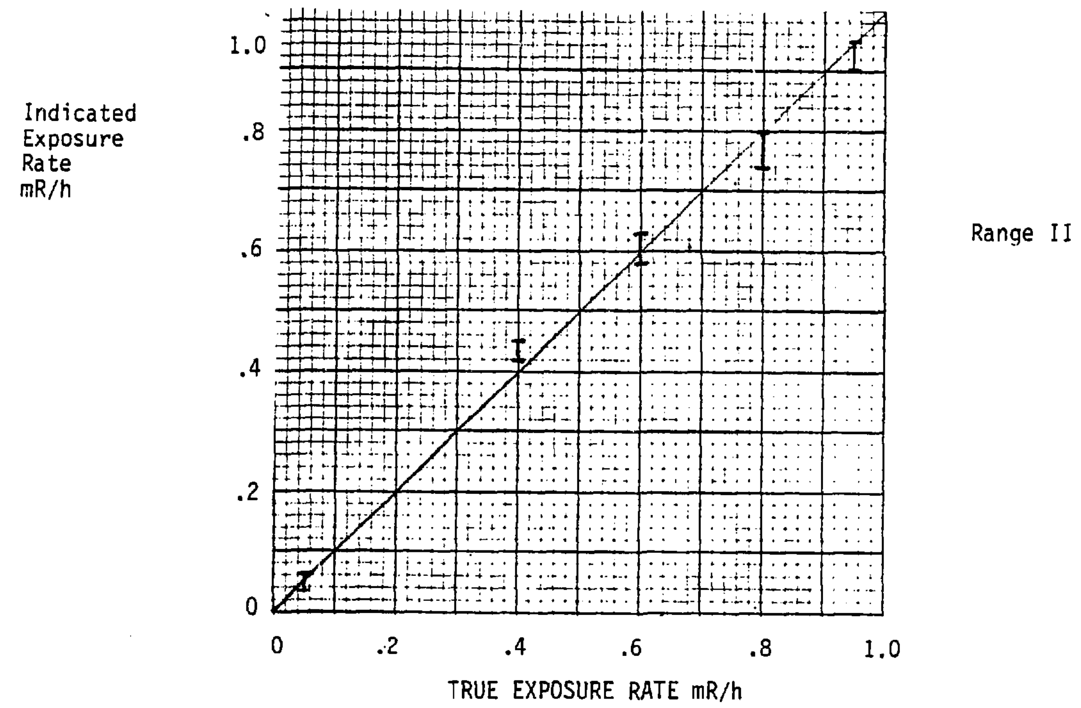


FIGURE 9.4

LINEARITY TEST OF LB1200 #40

RANGES I & II



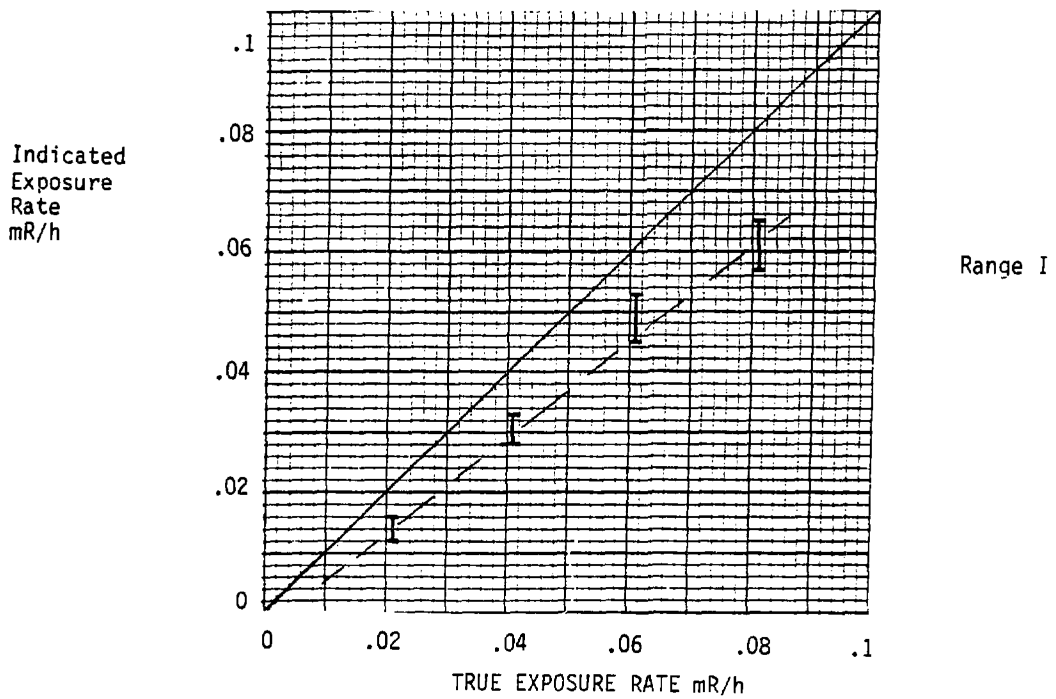


FIGURE 10.1

SLIT COLLIMATOR GEOMETRY FOR LB1200 MEASUREMENTS

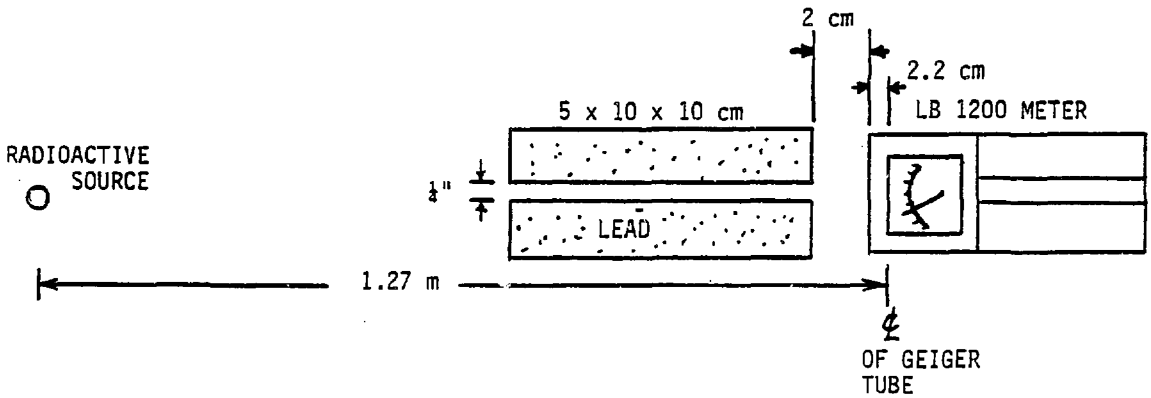
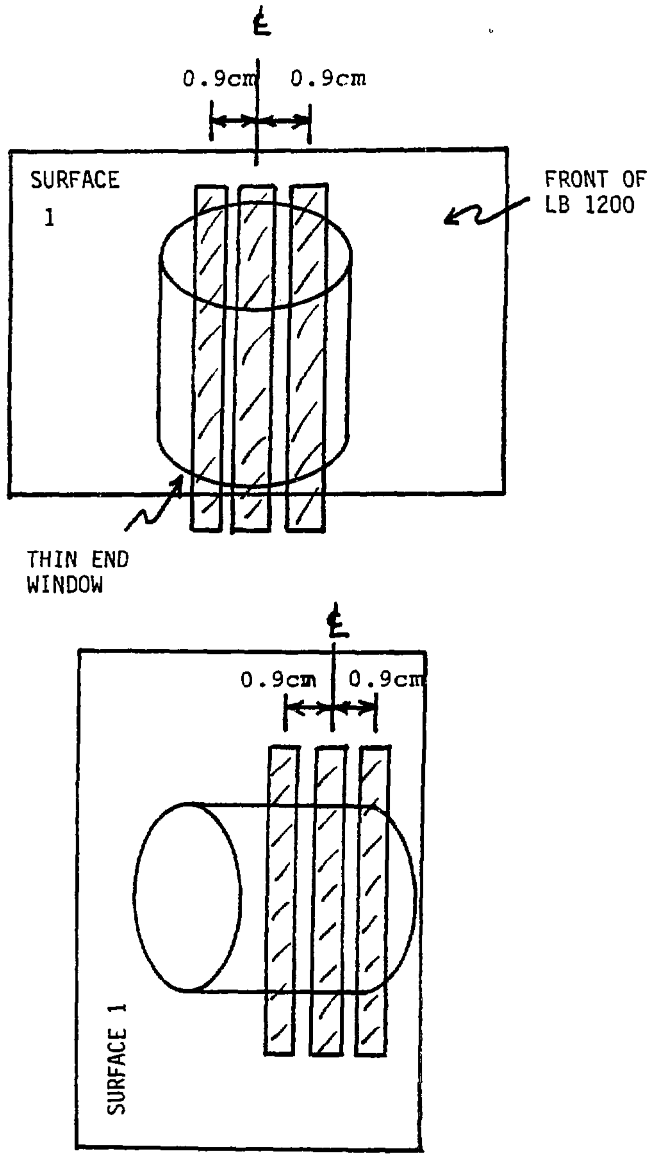


FIGURE 10.2

SLIT BEAM IRRADIATION OF LB1200 GEIGER TUBE



(a) VERTICAL

(b) HORIZONTAL

FIGURES 10.3

PENCIL BEAM (3/8" DIAMETER) MEASUREMENTS USING

LB1200 GEIGER TUBE

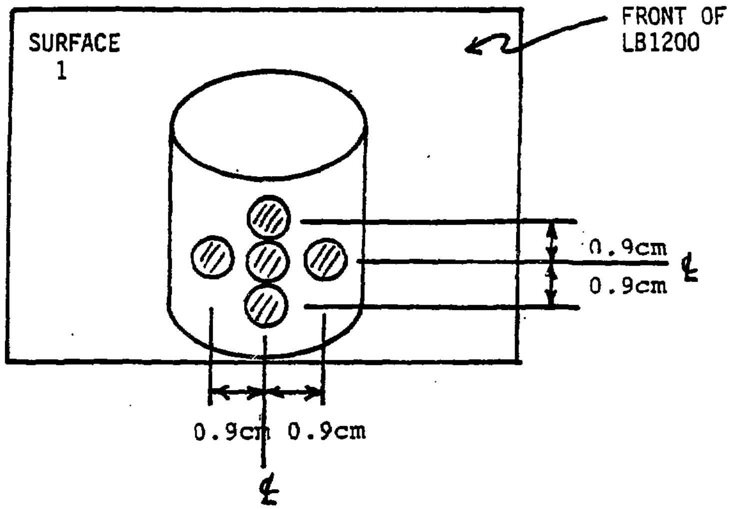


FIGURE 10.4

PENCIL BEAM RESULTS PLOTTED WITH GEIGER TUBE VOLUME RATIOS

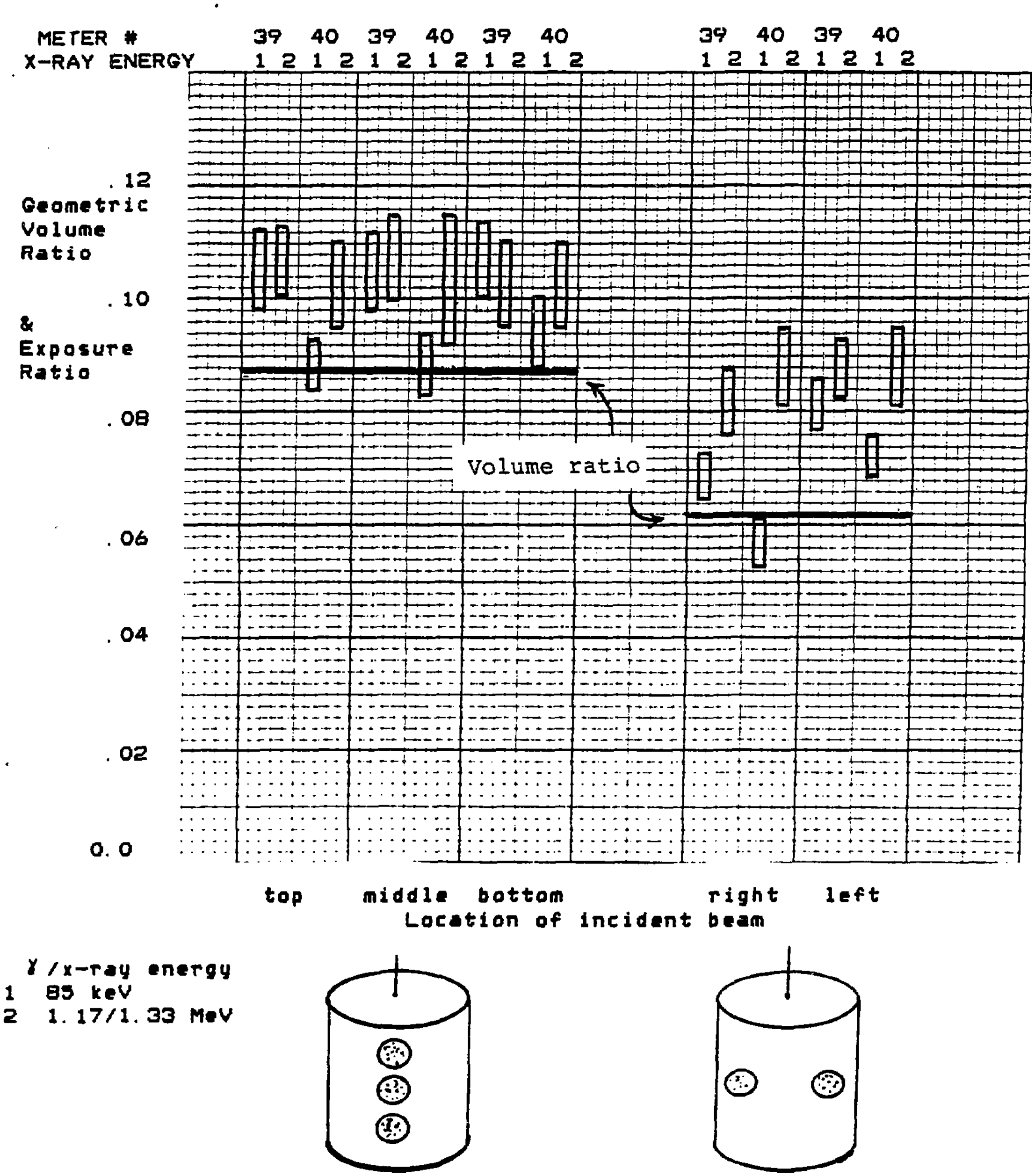


FIGURE 10.5

SLIT BEAM RESULTS PLOTTED WITH GEIGER TUBE VOLUME RATIOS
GAMMA ENERGY 1.17/1.33 MeV

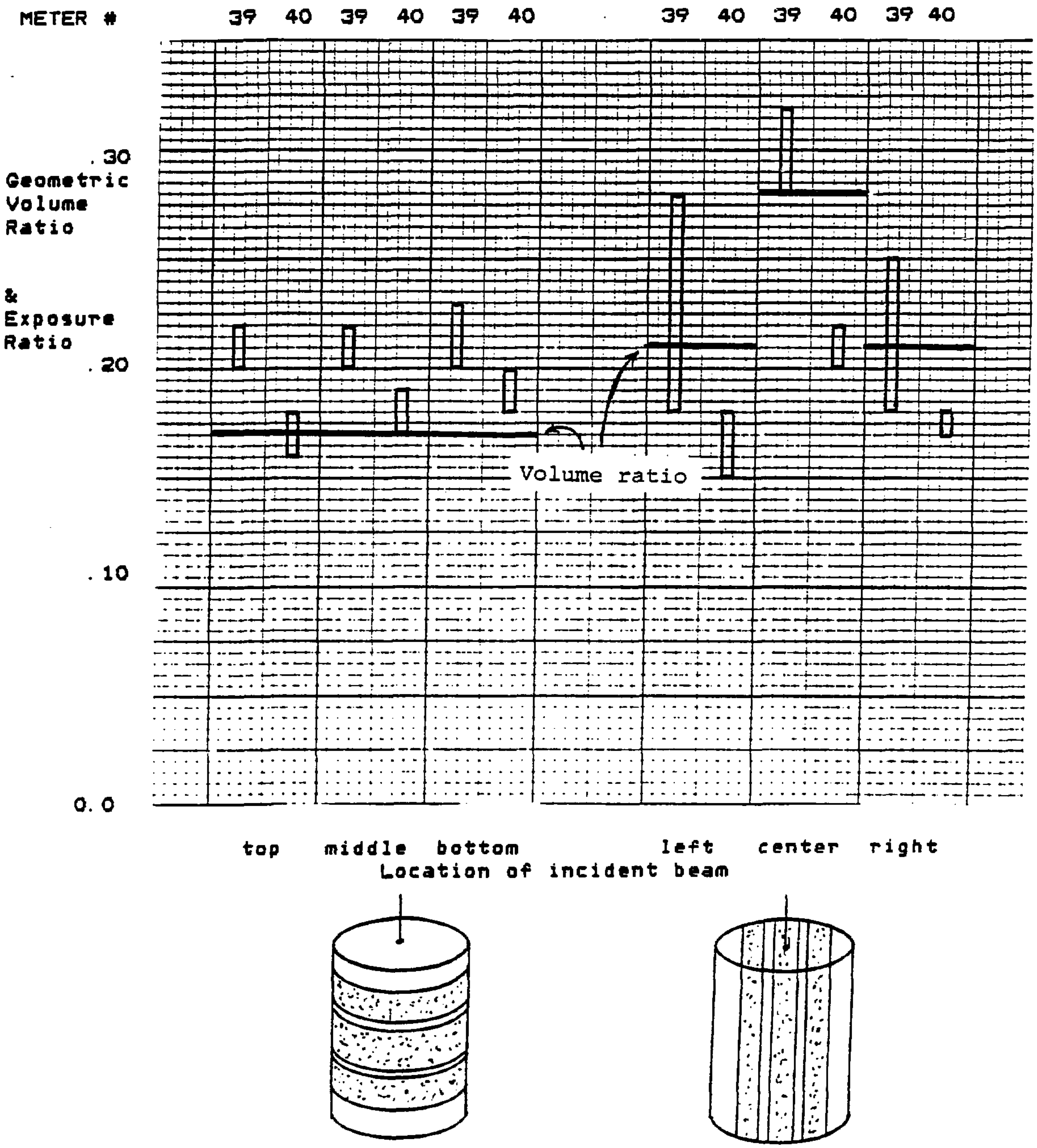
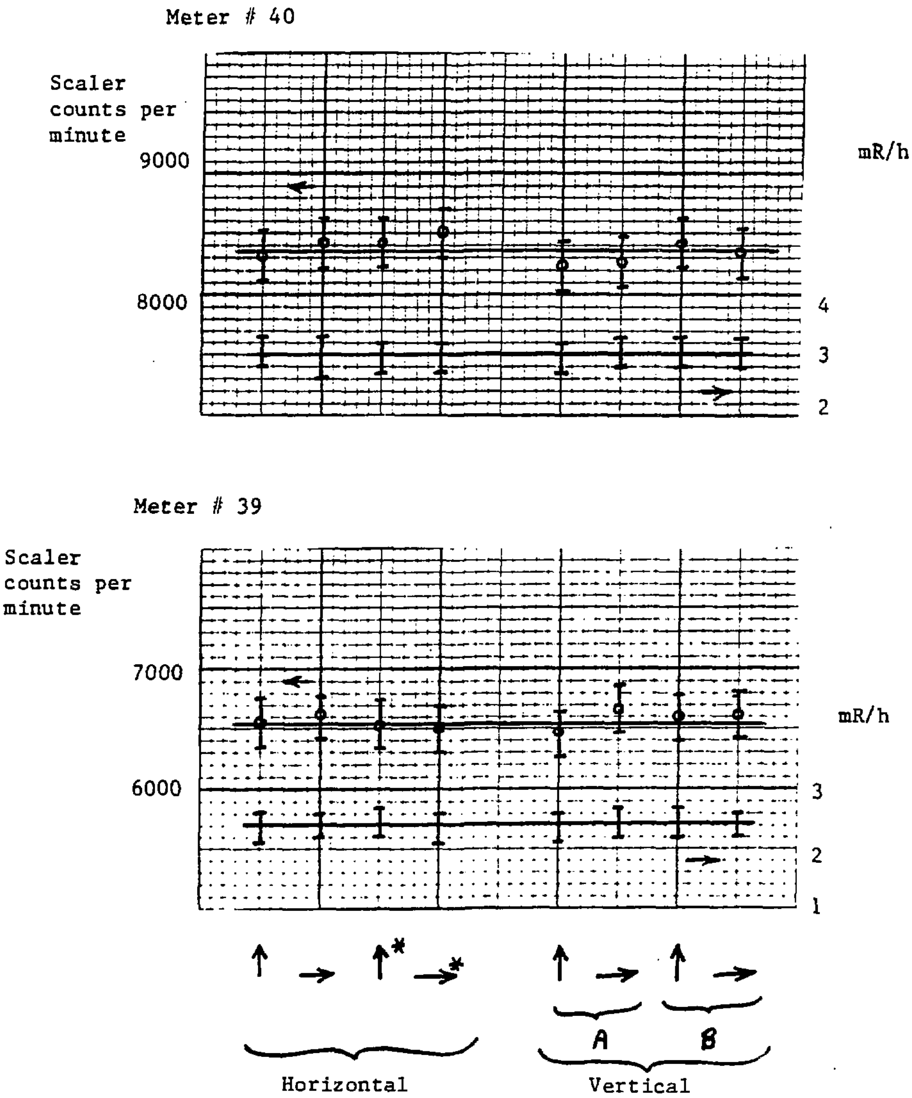


FIGURE 11.1

GEOTROPIC AND GEOMAGNETIC RESPONSE



* upside down A perpendicular to B

Scaler Count and +/-2 standard deviations
Range of Analog meter fluctuations

TABLE 6.1

RF INTERFERENCE ON METER 40, 30 - 1000 Hz

METER #40, SURFACE 4, VERTICAL POLARIZATION, 30 - 1000 Hz

POWER DENSITY mW/cm2	20	20	20	5	
SCALER cpm	11715	10782	11568	9003	9022*

METER#40, SURFACE 6, HORIZONTAL POLARIZATION, 30 - 1000 Hz

POWER DENSITY mW/cm2	20	20	14.8	9.5	
SCALER cpm	9535	11516	10817	9371	9200*

* AVERAGE COUNT ON OTHER SURFACES - NO INTERFERENCE

TABLE 10.1

RESPONSE OF LB1200 TO 1/4" SLIT BEAM IRRADIATION

TRUE EXPOSURE RATE IN AIR 4.34 mR/h
1.17/1.33 MeV C060

	METER #39		METER #40	
(a) VERTICAL BEAM	METER READING mR/h	CORRECTION* FACTOR	METER READING	CORRECTION* FACTOR
CENTER	1.4-1.6	3.1-2.7	.85 -.95	5.1-4.6
RIGHT	1.0-1.4	4.3-3.1	.65 -.72	6.7-6.0
LEFT	1.0-1.3	4.3-3.3	.72 -.77	6.0-5.6
(b) HORIZONTAL BEAM				
CENTER	.83 -.90	5.2-4.8	.77 -.83	5.6-5.2
TOP	.83 -.93	5.2-4.7	.72 -.80	6.0-5.4
BOTTOM	.85 -.95	5.1-4.6	.78 -.88	5.6-4.9

$$* \text{ CORRECTION FACTOR} = \frac{\text{TRUE EXPOSURE RATE IN AIR}}{\text{INDICATED EXPOSURE RATE}}$$

TABLE 10.2

RESPONSE OF LB1200 TO 3/8" PENCIL BEAM IRRADIATION

TRUE EXPOSURE RATE IN AIR 4.34 mR/h
1.17/1.33 MeV CO60

	METER #39		METER #40	
	METER READING mR/h	CORRECTION* FACTOR	METER READING mR/h	CORRECTION* FACTOR
CENTER	.45 -.52	9.6-8.3	.42 -.52	10.3-8.3
RIGHT	.35 -.40	12.4-10.9	.37 -.43	11.7-10.1
LEFT	.38 -.43	11.4-10.1	.37 -.43	11.7-10.1
TOP	.46 -.51	9.4-8.5	.43 -.50	10.1-8.7
BOTTOM	.43 -.50	10.1-8.7	.43 -.50	10.1-8.7

$$* \text{ CORRECTION FACTOR} = \frac{\text{TRUE EXPOSURE RATE IN AIR}}{\text{INDICATED EXPOSURE RATE}}$$

TABLE 10.3

RESPONSE OF LB1200 TO 3/8" PENCIL BEAM IRRADIATION
(85 keV)

	METER #39			METER #40		
	METER READING	TRUE EXPOSURE RATE mR/h	CORRECTION* FACTOR	METER READING mR/h	TRUE EXPOSURE	CORRECTION* FACTOR
CENTER	7.5-8.5	27.7	3.7-3.26	7.6-8.6	28.2	3.7-3.3
RIGHT	7.3-8.3	41.1	5.6-5.0	8.0-9.0	45.9	5.7-5.1
LEFT	8.3-9.3	39.3	4.7-4.22	7.5-8.3	33.6	4.2-3.7
TOP	7.5-8.5	27.3	3.6-3.2	7.5-8.5	28.2	3.8-3.3
BOTTOM	8.0-9.0	28.8	3.6-3.2	8.0-9.0	27.7	3.5-3.1

$$* \text{ CORRECTION FACTOR} = \frac{\text{TRUE EXPOSURE RATE IN AIR}}{\text{INDICATED EXPOSURE RATE}}$$

TABLE 10.4

VOLUME AND EXPOSURE RATE RATIOS FOR BEAM MEASUREMENTS

1/4" SLIT BEAM		VOLUME RATIO	EXPOSURE RATE RATIO METER #39 85 keV	METER #39 1.17 MeV	METER #40 85 keV	METER #40 1.17 MeV
1) Beam long dimension parallel to longitudinal axis of geiger tube	a) incident on tube centerline (CL)	0.28	–	.28–.32	–	.20–.22
	b) incident 9 mm to left of CL	0.21	–	.18–.28	–	.15–.17
	c) incident 9 mm to right of CL	0.21	–	.18–..25	–	.17–.18
2) Beam long dimension perpendicular to long axis of tube	a) top	0.17	–	.20–.22	–	.16–.18
	b) center	0.17	–	.20–.22	–	.17–.19
	c) bottom	0.17	–	.20–.23	–	.18–.20
PENCIL BEAM						
1) Beam incident upon longitudinal axis of geiger tube	a) top	0.087	.098–.112	.101–.113	.084–.093	.095–.111
	b) middle	0.087	.098–.112	.099–.115	.083–.094	.092–.115
	c) bottom	0.087	.101–.114	.095–.111	083–.094	.095–.111
2) Beam incident 9 mm off longitudinal axis of tube	a) left	0.0615	.077–.086	.083–.095	.069–.076	.081–.095
	b) right	0.0615	.065–.073	.076–.088	.053–.061	.081–.095

* the fraction of the active volume of the geiger tue intersected by the slit or pencil beam

APPENDIX 1

MODIFICATIONS TO LB1200 SURVEY METERS

Appendix 1: Modifications to LB1200 Survey Meters

Internal electrical connections were made via a multiwire cable within each of the survey meters so that several functions could be remotely controlled or monitored. The capability to remotely turn on, turn off and battery check the survey meters was added. Also, the pulsed ouput from the geiger counter was made available for scaling and two lines were connected so that the LB1200 battery voltage could be monitored externally by voltmeter.

The points at which electrical connections were made are shown on the circuit diagram Figure A1.1. The multiwire cable was passed through the external geiger tube receptacle in the LB1200 case and connected to a scaler and voltmeter as shown in Figures A1.2 and A1.3

FIGURE A1.1 LB1200 CIRCUIT DIAGRAM

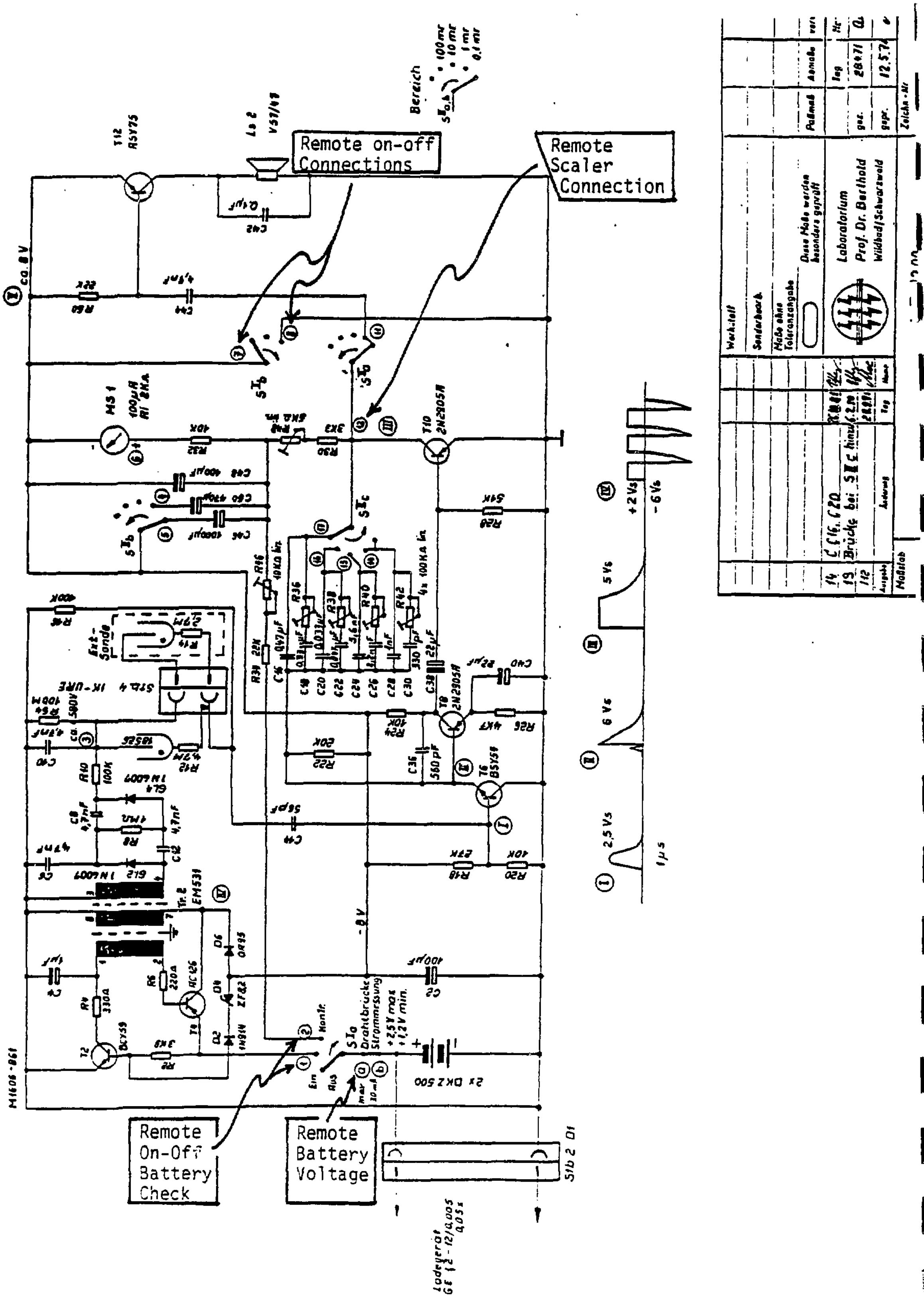


FIGURE A1.2

LB1200 SURVEY METERS IN KTS ENVIRONMENTAL CHAMBER

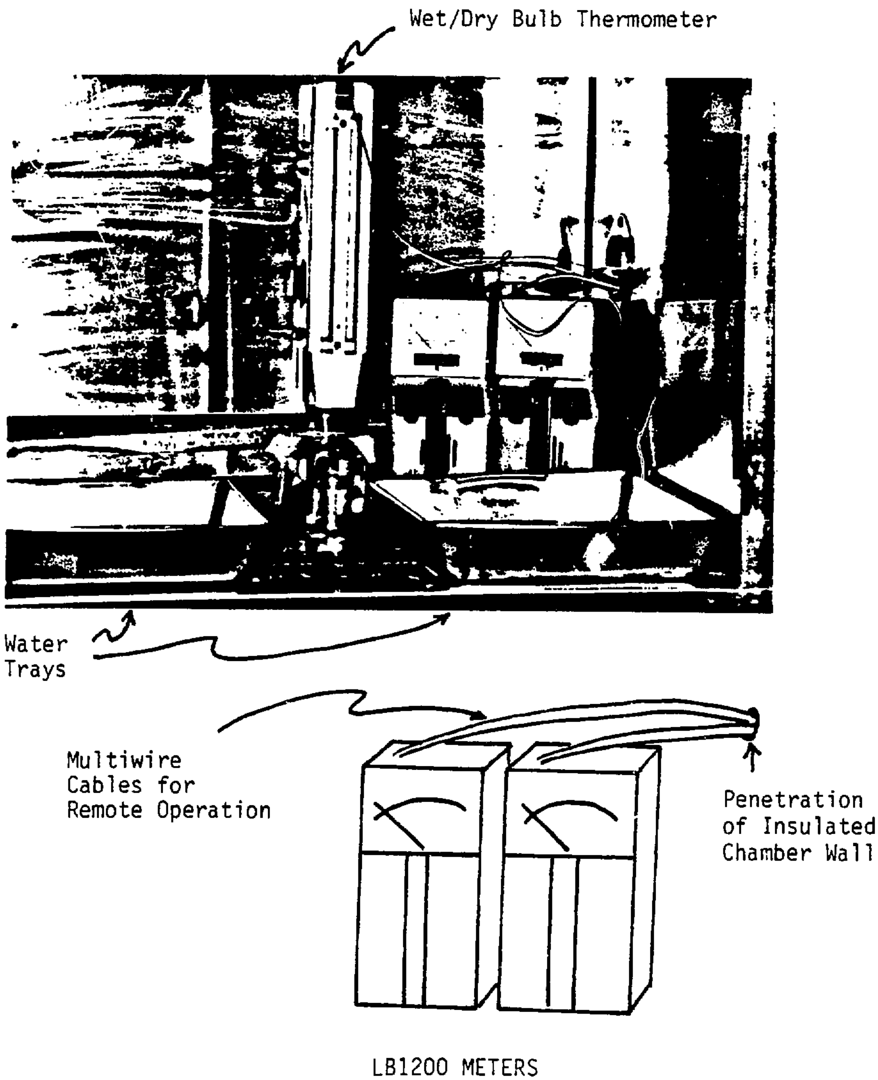
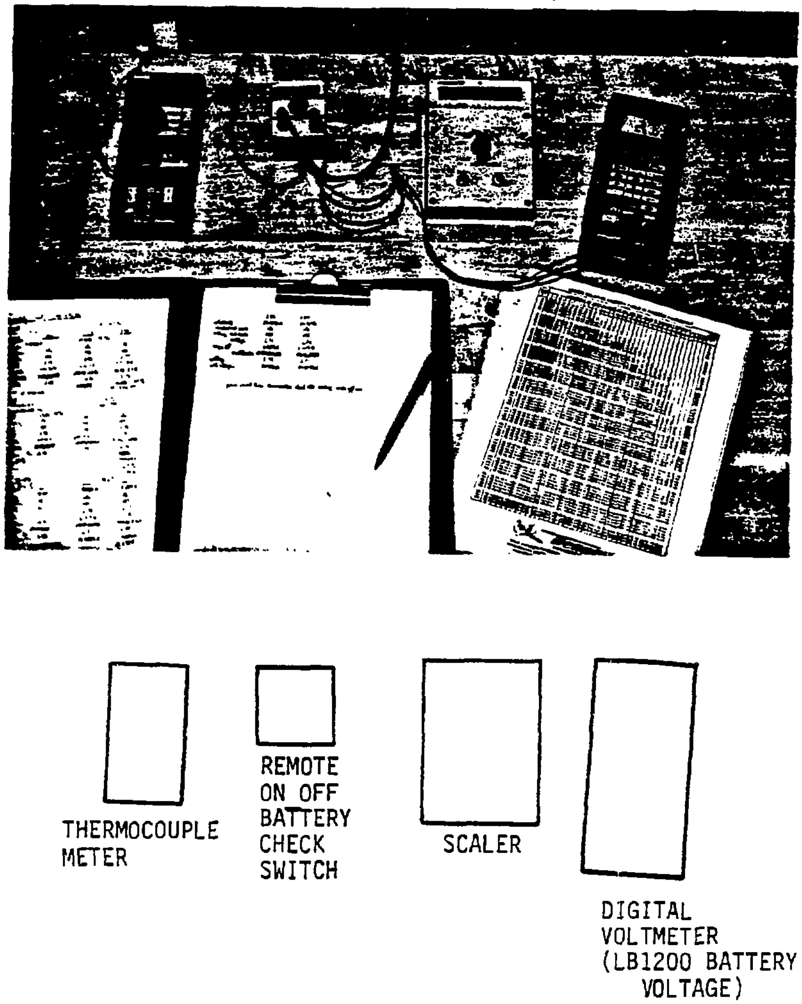


FIGURE A1.3

REMOTE METERS AND CONTROLLER FOR LB1200



APPENDIX 2

RAW DATA FROM GAMMA/X-RAY ENERGY RESPONSE MEASUREMENTS

TABLE A2.1

X-RAY ENERGY RESPONSE RESULTS

X-RAY GENERATOR VOLTAGE kV	FILTER mm pb	Sn	Cu	MEAN ENERGY keV	TARGET CURRENT mA	IONEX * READING mR/min.	IONEX CALIBRATION FACTOR	TEMP. AND PRESSURE CORRECT	TRUE EXPOSURE RATE IN AIR mR/h	LB1200 METER mR/h	SCALER COUNTS/MIN.
METER 39											
73	-	-	2.5	59	2.7-2.8	.269-.276	1.012	1.03	17.0	31-35	64244 64183
102	-	2.0	0.5	85	1.98-2.09	.195-.205	1.009	1.03	12.47	34-37	66243 66017
125	-	4.0	1.05	107	5.09-5.15	.221-.228	1.015	1.03	14.05	32-35	63820 64326
170	1.5	3.0	1.0	147	6.28-6.37	.326-.336	1.041	1.03	21.3	34-37	66452 66504
213	3.5	2.0	0.5	183	5.17-5.30	.402-.408	1.062	1.03	26.6	33-36	64425 65521
242	5.5	2.0	0.5	210	5.17-5.30	.409-.418	1.079	1.03	27.6	34-37	65388 65916
METER 40											
73	-	-	2.5	59	2.42-2.53	.266-.285	1.012	1.03	17.3	27-29	56397 54730
102	-	2.0	0.5	85	1.90-2.00	.174-.176	1.009	1.03	10.91	30-33	61571 61662
125	-	4.0	1.05	107	5.08-5.15	.221-.226	1.015	1.03	14.05	30-33	61086 60380
170	1.5	3.0	1.0	147	6.27-6.34	.314-.325	1.041	1.03	20.46	33-36	65105 65138
213	3.5	2.0	0.5	183	5.14-5.26	.406-.415	1.062	1.03	27.0	33-36	64215 64629
242	5.5	2.0	0.5	210	5.17-5.24	.408-.413	1.079	1.03	27.6	33-36	64910 65336

* FILTER A In Place

TABLE A2.2

CS137 GAMMA ENERGY RESPONSE RESULTS

METER S/N	IONEX * READING mR/min	IONEX+ CALIBRATION FACTOR	TEMP. & PRESSURE CORRECT	TRUE EXPOSURE RATE IN AIR mR/h	LB1200 METER mR/h	LB1200 SCALER COUNTS/MIN.
39	.515-.524	1.183	1.03	38.0	33-36	64455 65104
40	.508-.520	1.183	1.03	37.6	28-30	63907 63898

* FILTER 'B' IN PLACE

\+ FROM NRC CALIBRATION REPORT (for Co60)

TABLE A2.3

C060 GAMMA ENERGY RESPONSE RESULTS

METER S/N	FARMER* READING mR/h	SOURCE DETECTOR DISTANCE	LB1200 METER mR/h	LB1200 SCALER COUNTS/MIN
39	(20)	58.1	20-23	55692
40	(20)	58.1	19.5-21	49439

* 20 mR/h calculated at 58.1 cm from source by 1/r2 and FARMER DOSIMETER MEASUREMENT OF 12.49 mR in 10 minutes @ 30 cm with 600 cm3 CHAMBER

APPENDIX 3

RAW DATA FROM BETA ENERGY RESPONSE MEASUREMENTS

TABLE A3.1

BETA ENERGY RESPONSE RESULTS

RADIOISOTOPE	BETA ENERGY AVERAGE MeV	BETA ENERGY ENDPOINT MeV	INITIAL ACTIVITY uCi	INITIAL ACTIVITY DATE	PRESENT ACTIVITY DPM	METER S/N 39 SCALER CPM	METER S/N 39 METER CPM	METER S/N 40 SCALER CPM	METER S/N 40 METER CPM
C14	.049	.158	.131	11/8/80	290,820	5789	6500-8000	9879	11500-13000
						5716	6500-8000	9760	11000-13500
						5708	6500-8000	9802	11000-13500
PM147	.062	.225	.124	11/8/80	67,221	2418	2600-3500	3536	4000-4700
						2456	2700-3600	3406	4000-4700
						2557	2800-3800	3685	4000-4800
TC99	.085	.295	.049	11/8/80	108,780	7335	8500-9700	8998	10000-12000
						7218	8000-9500	9211	10500-12500
						7353	8500-10500	9253	10000-12000
Co60	.094	.319	.042	11/18/82	60,364	5313	6000-7500	6641	7500-9000
						5285	6000-7300	6487	7000-8500
						5347	6000-7500	6703	7300-9200
C136	.252	.714	.0222	8/19/80	49,284	8058	9000-11200	8682	10000-11500
						8032	9000-11000	8642	9700-11300
						8127	9200-11000	8695	9700-11500
Sr90	.200	.544	.0214	7/80	41,235	12731	15000-17500	13855	16500-18500
	.93	2.27				12871	15500-18000	13798	16500-19000
						12591	15000-17000	13792	16000-19000

APPENDIX 4

RAW DATA FROM TEMPERATURE RESPONSE MEASUREMENTS

TABLE A4.1
RAW DATA FROM TEMPERATURE RESPONSE MEASUREMENTS

	TEMP.	#39		#40	
		SCALER cpm	METER mR/h	SCALER cpm	METER mR/h
EXPERIMENT 1					
	20 C	11393 11356	4.8-5.2	8751 8641	3.5-4.1
	30 C	12102 11930	5.2-5.5	8728 8705	3.5-4.0
	20 C	11503 11321	4.8-5.3	8675 8582	3.5-4.0
EXPERIMENT 2					
	17 C	14570 14765	6.0-6.8	8878 9119	3.5-4.2
	0 C	15152 14762	6.2-7.2	9115 9497	3.7-4.3
	-10 C	14852 14677	6.2-7.0	9117 9205	3.7-4.2
	-20 C	14754 14880	6.2-7.0	9624 9225	3.8-4.5
	-30 C	15307 15057	6.2-7.2	9347 9699	3.8-4.5
	+17 C	14828 14702	6.4-7.1	9036 8937	3.7-4.2

APPENDIX 5

RAW DATA FROM HUMIDITY RESPONSE MEASUREMENTS

TABLE A5.1
RAW DATA FROM HUMIDITY RESPONSE MEASUREMENTS

RELATIVE HUMIDITY %	#39 SCALER cpm	#39 METER mR/h	#40 SCALER cpm	#40 METER mR/h
16 ambient	15100	6.5-7.5	9059	3.5-4.2
	15182		8929	
41-47	14917	6.2-7.2	9070	3.7-4.2
	14976		8919	
54-57	14980	6.5-7.2	8983	3.7-4.2
	15111		9070	
66-73	14925	6.5-7.2	9175	3.7-4.2
	15015		8854	
79-83	15041	6.5-7.2	8903	3.5-4.2
	14880		9049	
86-90	14857	6.3-7.0	9063	3.7-4.2
	14745		8964	
94	14734	6.2-7.2	8902	3.5-4.2
	14697		8869	
16 ambient	14758	6.5-7.2	8902	3.5-4.2
	14746		8945	

APPENDIX 6

RAW DATA FROM RADIOFREQUENCY INTERFERENCE MEASUREMENTS

TABLE A6.1

RADIOFREQUENCY INTERFERENCE RESULTS

FREQ'CY RANGE HZ	POWER DENSITY mW/cm2	WAVE FORM	METER S/N	VERTICAL POLARIZATION						HORIZONTAL POLARIZATION					
				1	2	3	4	5	6	1	2	3	4	5	6
30 TO	20	CW	39	14726	14881	14975	14656	14666	15042	14966	15111	14882	15088	14734	15034
1000	20	CW	40	9206	9156	9028	8925	9212	8962	9004	9146	8958	9204	9094	9060
30 TO	20	P	39	15056	14732	14790	14911	14912	15062	14775	15066	15014	14901	15069	14998
1000	20	P	40	9253	8958	9033	10782	8971	8896	9410	8949	9035	9481	9127	9535
1k TO	20	CW	39	14928	14688	14756	14830	14917	14984	14849	14741	15069	15016	14791	14921
100k	20	CW	40	8984	8990	8919	9027	8994	9025	8917	9005	9046	9109	9059	9091
1k TO	20	P	39	14978	14659	14745	14872	14919	14931	14784	15023	14832	14885	14895	15243
100k	20	P	40	9035	9010	9102	9059	8912	9040	9100	9256	9017	9001	9064	8967
100k TO	20	CW	39	3900	3863	3799	3865	3900	3882	4033	3793	3915	3978	3946	3907
5M	20	CW	40	8655	8633	8718	8648	8694	8693	8566	8988	8673	8709	8622	8648
100k TO	20	P	39	3939	4034	3808	3919	3973	3862	3990	3991	3901	3960	3885	3951
5M	20	P	40	8745	8576	8757	8660	8519	8685	8545	8689	8578	8778	8537	8560
5M TO	1	CW	39	3890	3998	3944	3838	3981	3996	3941	3895	3956	3964	3945	3957
30M	1	CW	40	8505	8720	8617	8501	8585	8592	8619	8619	8685	8776	8660	8498
5M TO	1	P	39	3891	3959	3989	3895	3908	3985	4010	4079	3864	3977	4000	4087
30M	1	P	40	8487	8689	8651	8513	8779	8705	8783	8657	8646	8696	8710	8732
30M TO	1	CW	39	15020	14957	14836	14955	14608	14826	14966	14990	4726	14771	14834	14763
140M	1	CW	40	8975	8954	9005	8977	8993	9109	9087	8931	8875	8828	9079	9036
30M TO	1	P	39	14875	14760	15089	14749	14715	14551	14826	14710	14779	14734	14891	14521
140M	1	P	40	8979	9074	9188	9017	9093	9027	9027	8962	8960	9023	8847	9054
140M TO	1	CW	39	14935	15011	14926	14845	14956	14951	15027	15141	15063	14811	14899	14891
400M	1	CW	40	9056	8998	9103	9121	9192	8987	9031	9044	8964	9080	8905	9005
140M TO	1	P	39	14868	15087	14964	14675	14849	14780	14772	14793	14755	14648	14806	14944
400M	1	P	40	8953	8940	8917	9165	9084	9109	8999	8988	9010	9004	9190	8970
400M TO	1	CW	39	14528	14960	14890	15033	14697	15022	14805	15051	14767	14773	14898	14773
1G	1	CW	40	9005	9064	8977	9020	9032	8852	9052	8970	8988	8878	9142	9058
400M TO	1	P	39	14827	15108	14744	14784	14768	14895	14874	14805	14731	14653	14879	15158
1G	1	P	40	9117	9045	9013	8996	8982	9018	9090	8946	9018	9020	9115	9160

APPENDIX 7

STANDARD FOR RADIOFREQUENCY INTERFERENCE TEST

SAMA STANDARD

PMC 33.1-1978

ELECTROMAGNETIC SUSCEPTIBILITY OF PROCESS CONTROL INSTRUMENTATION

SCIENTIFIC APPARATUS MAKERS ASSOCIATION

FOREWORD

This Foreword is supplied for informational purposes, only, and is not part of SAMA Standard Electromagnetic Susceptibility of Process Control Instrumentation, PMC 33.1-1978.

Scientific Apparatus Makers Association Standards are adopted in the public interest and are designed to eliminate misunderstandings between the manufacturer and the purchaser and to assist the purchaser in selecting and obtaining without delay the proper product for his particular need.

Existence of a SAMA Standard or a Proposed SAMA Standard does not in any respect preclude any member or non-member from manufacturing or selling products not conforming with the standard.

Most electronic equipment is in some manner affected by electromagnetic radiation. This radiation is frequently generated by the small hand-held radio transceivers that are used by maintenance and security personnel. The susceptibility of Process Control instrumentation to the radiation of the hand-held transceiver is the primary concern of this standard. However, there are other sources of electromagnetic radiation of concern, such as fixed station radio and television transmitters, vehicle radio transmitters and various industrial electromagnetic sources.

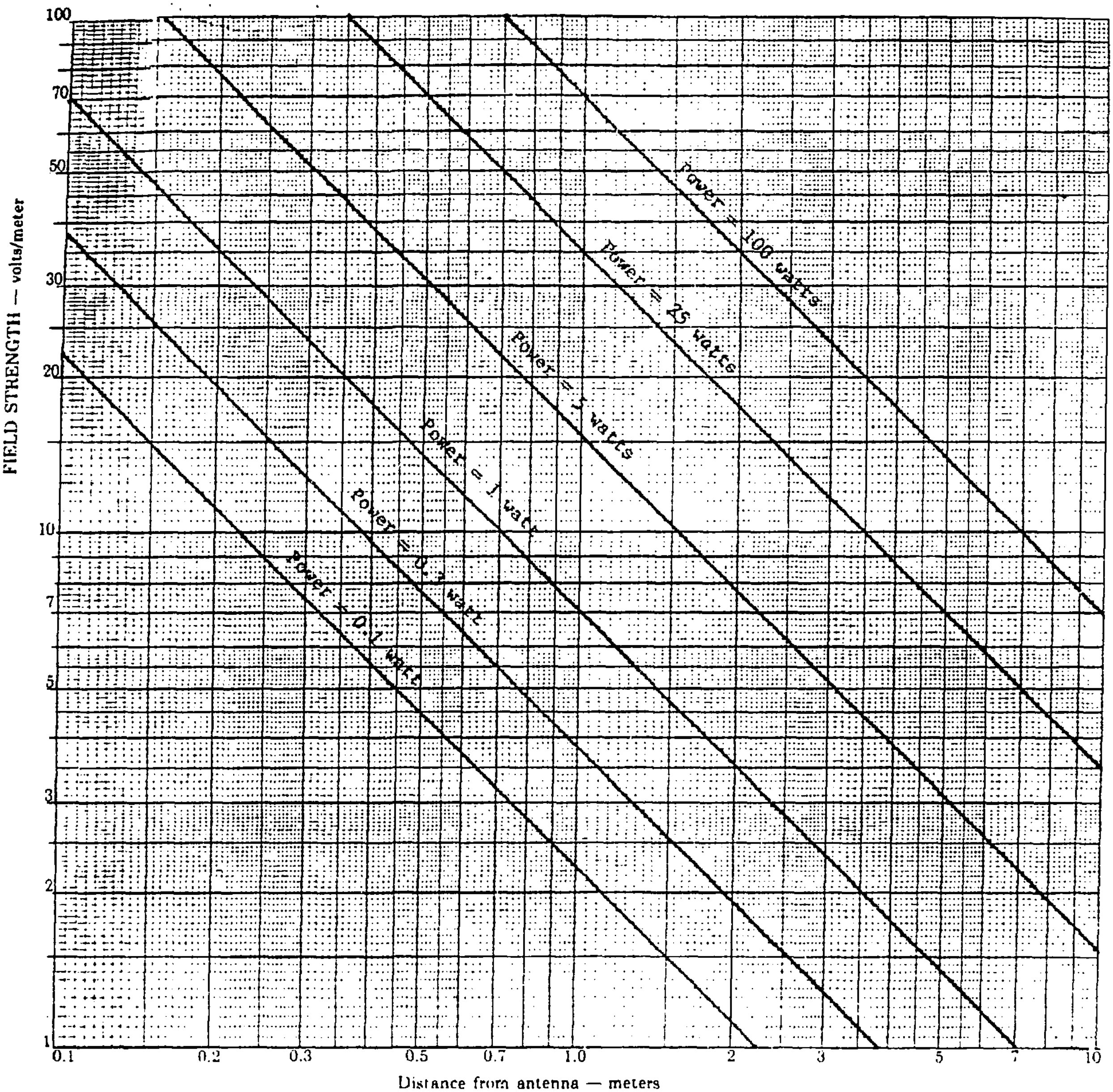
In addition to the continuous forms of electromagnetic energy deliberately generated, there are also spurious radiations caused by devices such as welders, contactors, motors, etc. It is recognized that these sources can cause difficulties in the operation of equipment but they are beyond the present scope of this standard; however, methods employed to prevent effects from continuous radiation will normally also reduce the effects from these sources.

The electromagnetic environment is determined by the strength of the electromagnetic field (field strength in volts per meter). The field strength is not easily measured without sophisticated instrumentation nor is it easily calculated by classical equations and formulae because of the effect of surrounding structures or the proximity of other equipment that will distort and/or reflect the electromagnetic waves.

The graph on page 2 is provided as a guideline of what the field strength may be in the proximity of a source of electromagnetic radiation from a 1/2 wave dipole antenna in an isotropic space in the far field. Because of the factors listed above it should only be used as an approximation and tests should be conducted on the installed equipment to insure that the desired effects have been achieved.

Test methods are defined in the standard for measuring the effect that electromagnetic radiation has on the instrument of concern. The test methods defined are structured for the primary objective of establishing repeatability of results at various test sites. However, electromagnetic radiation will be affected and distorted by the proximity of conductive objects, including the walls of the test chamber. Therefore, there will undoubtedly be some differences in results if tests are conducted at various sites. These differences must be taken into account when verification testing is conducted.

This standard is written for those knowledgeable of electromagnetic interference problems and methods of analyzing and limiting the effect. It is not intended to be a tutorial standard. Tutorial information can be obtained by referring to the bibliographical references.



Approximate Field strength in the far field from a dipole antenna as a function of antenna power based on equation $E = \frac{7.02}{d}\sqrt{P}$ for $d \geqslant \frac{\lambda}{2\pi}$

(d = distance from antenna in meters, P = radiated antenna power)

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ELECTROMAGNETIC SUSCEPTIBILITY OF PROCESS CONTROL INSTRUMENTATION

1. SCOPE

This standard applies to the susceptibility of industrial and process control instrumentation to radiated electromagnetic energy. This standard establishes a classification of environments for anticipated electromagnetic fields and defines test methods for evaluating the instrumentation when used in these electromagnetic environments.

2. PURPOSE

The purpose of this standard is to establish a common reference for evaluating the performance of industrial process control instrumentation when subjected to electromagnetic fields such as generated from portable radio transceivers (walkie-talkies), or any other device that will generate continuous wave radiated electromagnetic energy.

3. DEFINITIONS, TERMINOLOGY, AND BIBLIOGRAPHY

3.1 Definitions and Terminology

Amplitude Modulation: The process by which the amplitude of a carrier wave is varied in accordance with a modulating wave.

Antenna: A transducer which either emits radio frequency power into space from a signal source, or intercepts an arriving electromagnetic field, converting it into an electrical signal.

Continuous Waves: (CW) Electromagnetic waves, the successive oscillations of which are identical under steady-state conditions, which can be interrupted or modulated to convey information.

Electromagnetic Interference (EMI): Any spurious effect produced in the circuits or elements of a device by external electromagnetic field.

Electromagnetic Wave: The radiant energy produced by the oscillation of an electric charge characterized by oscillation of the electric and magnetic fields.

Far Field: That region where the field from an antenna is self-propagating. For a dipole antenna this corresponds to distances greater than $\frac{\lambda}{2\pi}$, where λ is the wave length of the radiation.

Field Strength: The magnitude of the electromagnetic field, expressed as volts/meter.

Frequency Band: A continuous range of frequencies extending between two limits.

Isotropic: Having properties of equal values in all directions.

Octave: A frequency ratio of 2 to 1. 3.32 octaves equal one decade.

Polarization: A term used to describe the orientation of the electric-field vector of a radiated field.

Shielded Enclosures: A screened or solid metallic housing designed expressly for the purpose of isolating the internal from the external electromagnetic environments. The purpose is to prevent outside ambient electromagnetic fields from causing performance degradation and to prevent emission from causing interference to outside activities.

Sub-harmonic: An integer sub-multiple of a fundamental frequency.

Radiation: The propagation of a signal or interference from a source other than by conduction.

Span: The algebraic difference between the upper and lower range values.

Spurious Radiation: Any undesired electromagnetic emission from an electrical device.

Susceptibility: The characteristic of electronic equipment that results in undesirable responses when subjected to electromagnetic energy.

Sweep: A continuous traverse over a range of frequencies.

Transceiver: The combination of radio transmitting and receiving equipment in a common housing.

The above definitions were extracted from MIL-STD-463; IEEE Std 100-1972—ANSI C42.100-1972; SAMA PMC 20.1—1973; and ISA S51.1—1976, with modifications to fit the particular need of this standard.

3.2 Bibliography

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4. TEST CLASSIFICATIONS

4.1 The susceptibility tests have been classified according to field strengths and frequency bands. This is to allow the manufacturer or user to describe the susceptibility of instruments more accurately because susceptibility may vary with frequency as well as field strength.

4.2 The classes of field strengths are shown in Table 1; the frequency bands are shown in Table 2.

TABLE 1
CLASS OF FIELD STRENGTHS

Class	Field Strength V/m
1	3
2	10
3	As specified

Class 1 - Low level electromagnetic radiation environments, e.g., local radio/television stations, low power transceivers.

Class 2 - Moderate electromagnetic radiation environments, e.g., portable transceivers or mobile transceivers that can be relatively close to the equipment but not closer than one meter.

Class 3 - Open class for situations involving very severe electromagnetic radiation environments. The level subject to negotiations between the user and vendor, or as defined by the manufacturer.

TABLE 2
FREQUENCY BANDS

Band	Frequency Range MHz
a	20-50
b	50-300
c	300-1000

The identifying nomenclature for the equipment is composed by stating the classes and bands followed by the numerical value of the maximum error of the instrument as shown by figure 1

Example 1 — 1-c:0.5% Span.
This describes a device that has been tested for only class 1 (3 V/m) and band c (300 to 1000 MHz) and shows an error of not greater than 0.5% span.

Example 2 — 3-bc:1% Reading @ 50 V/m
This describes a device that has been tested for class 3 and bands b and c (50 to 1000 MHz) and shows an error of not greater than 1% of reading at specified level of 50 V/m.

Example 3 — 2-ab:0.75% span; 3-c:0.75% span @ 20 V/m
This describes a device that has been tested for class 2 (10 V/m) at frequencies of 20 to 300 MHz with an error no greater than 0.75% and class 3 at frequencies of 300 to 1000 MHz, with an error of no greater than 0.75% of span at specified level of 20 V/m.

Example 4 - 2-abc: Spec. 7P81.
This describes a device that has been tested for class 2 (10 V/m) over the full frequency range of 20 to 1000 MHz. The effect on the performance must be described in the product (or system) specification number 7P81.

5. TEST METHODS

5.1 TEST SET-UP

5.1.1 The procedure defined herein requires the generation of electromagnetic fields within which the test sample is placed and its operation observed. To generate fields that are useful for simulation of actual (field) conditions may require significant antenna drive power and the resultant high field strength levels. To cumply with the Federal Communication Commission's regulations and to prevent biological hazards to the testing personnel, it is recommended that these tests be carried out in a shielded enclosure or room.

5.1.2 The use of a shielded enclosure, however, creates difficulties in establishing and maintaining the required field strengths due to reflections of the radiated energy from the walls of the enclosure. These reflections will cause enforcement and cancellation nodes to be established within the room.

5.1.3 The calibrated span and other operational adjustments of the test sample during the testing shall be stated by the manufacturer in his documentation.

5.1.4 All testing on instruments shall be performed in as close to installed conditions as possible. Wiring shall be consistent with the manufacturer's recommended procedures and the instrument shall be in its housing with all covers and access panels in place, unless otherwise stated. If the equipment is designed to be mounted in a panel, rack or cabinet it should be tested in this configuration.

5.1.5 A specific ground plane is not required. When a means is required to support the test sample it should be constructed of non-metallic material. However, grounding of housing or case of the instrument shall be consistent with the manufacturer's installation recommendations

ELECTROMAGNETIC SUSCEPTIBILITY OF PROCESS CONTROL INSTRUMENTATION

Test Classifications

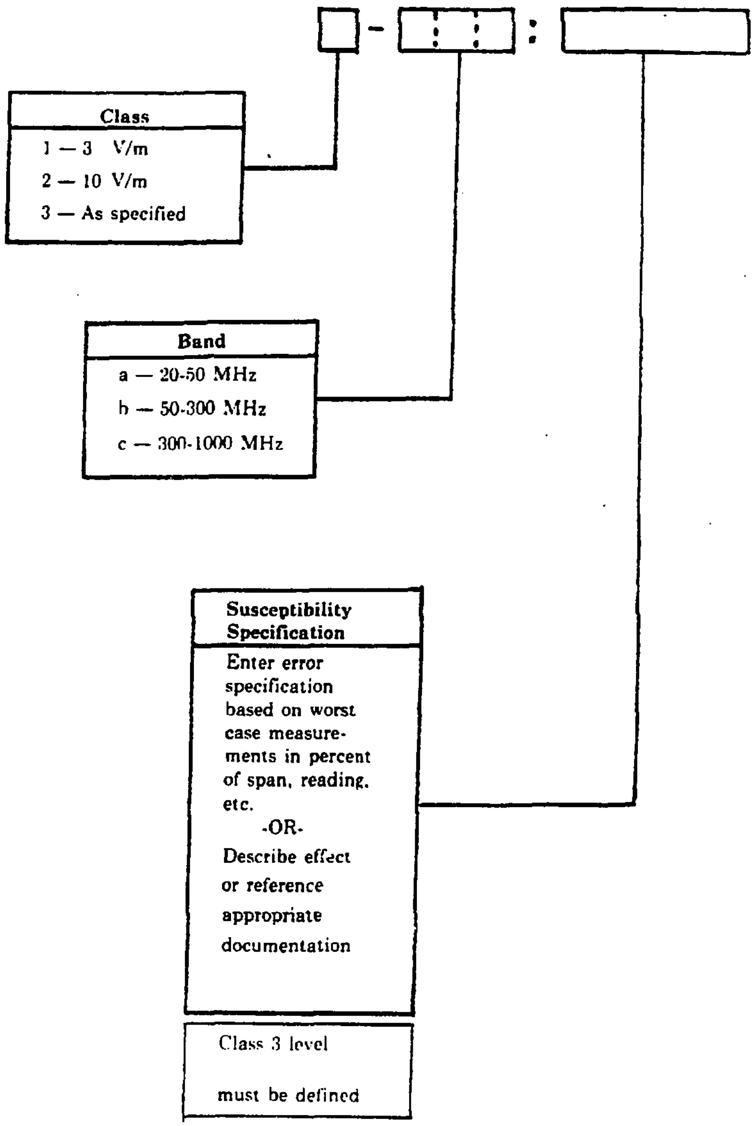

Figure 1 Specifying Test Classifications

5.2 TEST EQUIPMENT

5.2.1 The following test equipment is recommended. The use of other means of establishing and controlling the field is not ruled out and is acceptable providing the required conditions can be verified.

(1) Shielded Room—Size adequate to maintain distances shown by Figure 2.

(2) Signal Source—Signal generator(s) capable of covering frequency range with capability of amplitude modulation (if automatic sweep, sweep rate should be capable of achieving 0.005 octave/sec. (1.5×10^{-3} decades/sec.) or slower).

(3) Power Amplifier—To amplify signal and provide antenna drive if signal source is incapable.

(4) Antennas—Signal Source

a. Biconical } See Manufacturer's
b. Conical Logarithmic Spiral } Specifications

(5) Field Strength Monitor—Antennas with EMI Meter

(6) Associated equipment to monitor output and to establish operating power and signals for test sample.

5.3 TEST PROCEDURE

5.3.1 The test procedure assumes the use of biconical and log spiral antennas. Other methods of establishing the fields are acceptable providing the proper fields can be generated and verified.

5.3.2 Basic Radiation Susceptibility Test

(1) Set up the test sample and the transmitting antenna in accordance with the distance restrictions of Figure 2 for the biconical and log spiral antennas. When using the biconical transmitting antenna, adjust it so the electromagnetic field is polarized vertically.

(2) Establish the field strength at all frequencies of interest by replacing the test sample with the EMI receiver antenna.

(3) Replace the receiving antenna with the test sample and sweep through the required frequency band plotting the test sample output vs. the radiation frequency. Automatic sweep rate will be at 0.005 octaves or less per sec. If manual sweep is utilized, data points should be taken at a rate of three (3) frequencies per octave. For frequencies below 50 MHz,the test shall be run with amplitude modulation of 90% with a 1000 Hz sine wave. (See 5.3.3 for digital equipment).

(4) Step 3 shall be repeated to expose the test sample in other planes. The front and the back of the panel, rack or cabinet mounted equipment shall be exposed. Field mounted equipment shall be exposed on all six (6) sides.

(5) When using the biconical antenna, change electromagnetic wave polarization to horizontal and repeat Steps 2, 3, and 4.

5.3.3 Digital Equipment Modulation Test

All digital equipment using a clock shall also be subjected to electromagnetic radiation that is 90% amplitude (pulse or square wave) modulated at a frequency close to 10 kHz but not phase locked with the digital clock frequency. This applies to all test classification frequency bands. The 1000 Hz sine wave modulation listed in Step 3 above may be omitted when the 10 kHz modulation test is performed.

5.3.4 Keying Test

Some equipment is susceptible to repeated operation of a transmitter. This test is to evaluate the instrument in this mode. To simulate keying of a transceiver the signal source shall be switched between 0 and 100% of the CW amplitude as defined by 5.3.2(3). The switched signal shall have an on and off duration of at least one second each and shall have rise and fall times of no greater than 50 micro sec. There shall be at least three keying cycles per frequency octave. If manual sweep is utilized the test shall be run at three frequencies per octave. Exposure shall be to the most susceptible side of the instrument as defined by 5.3.2. (4).

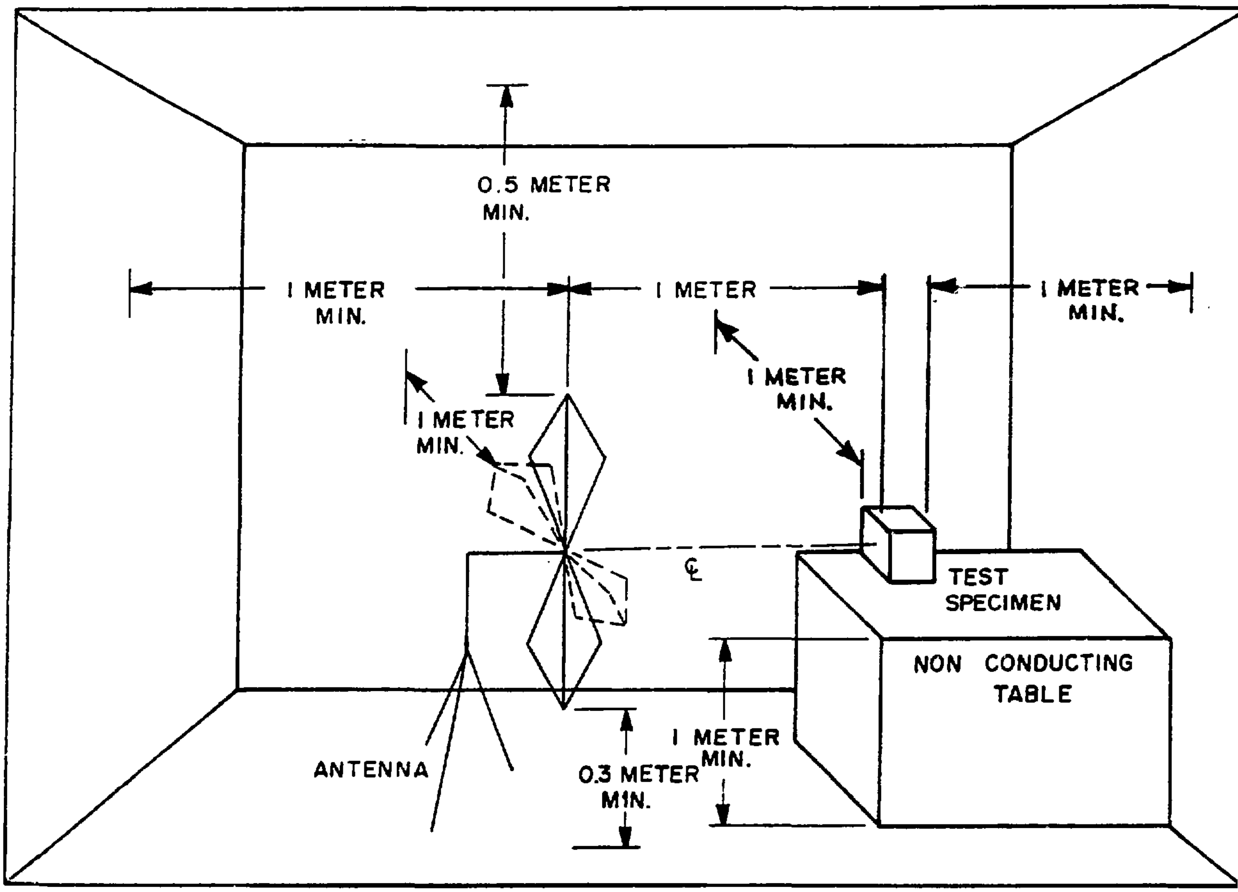

FIG. 2 TEST SET UP FOR RADIATED SUSCEPTIBILITY